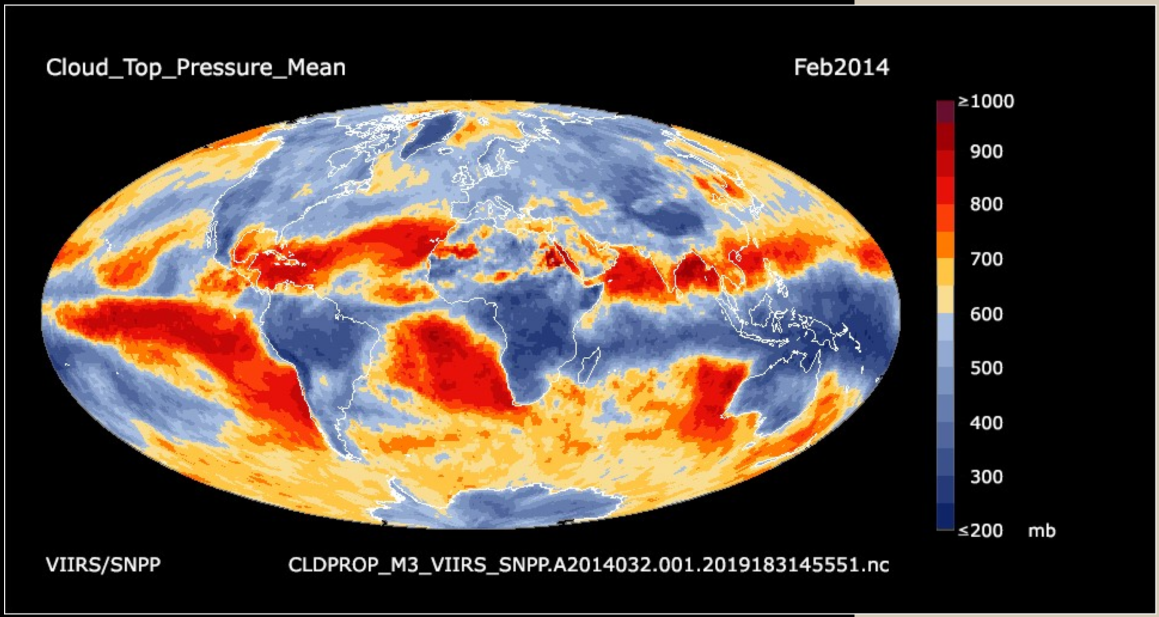
Level-3 Continuity Cloud Properties (CLDPROP_L3)
Global Gridded Product
User Guide



Continuity Atmosphere L3 CLDPROP
(MODIS Aqua, VIIRS SNPP, & VIIRS NOAA20)
Global Gridded Products for Daily (D3) and Monthly (M3)
User Guide

L3 CLDPROP User Guide, Version 2.0, 9 March 2021

Paul Hubanks[1], Steven Platnick[2], Kerry Meyer[2], Michael King[3], Steve Ackerman[4], Bob Holz[4], Andy Heidinger[4], Yue Li[4], Rich Frey[4], Andi Walther[4], Steve Dutcher[4], Paolo Veglio[4], Greg Quinn[4], Denis Botambekov[4], Gala Wind[5], Nandana Amarasinghe[5], Chenxi Wang[2], Benjamin Marchant[2], Bhaskar Ramachandran[5]

[1] Adnet Systems, Lanham, MD
[2] Earth Sciences Division, NASA Goddard Space Flight Center, Greenbelt, MD
[3] Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO
[4] CIMSS, University of Wisconsin, Madison, WI
[5] SSAI Corp, Lanham, MD

TABLE OF CONTENTS

1.0. Introduction

1.0.1. Background

NASA ushered in a new generation of global imager observations of the Earth with MODIS on the EOS Terra and Aqua missions. MODIS provides unique spectral capability relative to earlier global imagers, allowing for the retrieval of geophysical parameters key to understanding changes in the Earth's land surface, ocean, and atmosphere. To date, these imagers have proved remarkably successful, exceeding their design lives to produce 18-year (Terra) and 16-year (Aqua) climate data records that are expected to continue into the early 2020s.

Nevertheless, detecting climate trends, including those related to clouds, is a multi-decadal endeavor (typically greater than 2-3 decades) given the uncertainties of current sensors [*Wielicki et al.*, 2013]. Therefore, while the EOS Aqua and Terra missions are projected to extend into the early 2020s, those data records alone are not sufficient for establishing climate trends. Extending these EOS data records to new sensors is therefore imperative.

For continuing MODIS-like global cloud records, the only viable imager is VIIRS (375-750 m nadir resolution) on Suomi NPP (SNPP) and the operational NOAA JPSS series (starting with JPSS-1/NOAA-20 in late 2017, with subsequent satellites expected to provide coverage into the mid-2030s). For this reason, a merged MODIS-VIIRS cloud record to serve the science community in the coming decades requires different algorithm approaches than those used for MODIS alone.

Starting in 2013, NASA formed the SNPP Science Team to develop continuity algorithms that would bridge the EOS and SNPP observation era. Due to the differing characteristics between MODIS and VIIRS, the approach taken was to develop a continuity algorithm that uses common (or near-common) logic to be run on both the MODIS and VIIRS data streams.

1.0.2. Level 3 (L3) Atmosphere Data Production & Archive

Level 3 (L3) Atmosphere data users should note that in terms of production and availability, the Standard MODIS L3 cloud products, MOD08 (Terra MODIS) & MYD08 (Aqua MODIS), in production since 2000 and 2002 respectively, will continue to be produced.

Starting in 2019, Continuity L3 cloud products (CLDPROP_L3) will be added to the data record. Both the L3 Continuity products (CLDPROP) and L3 MODIS Standard products (MOD08 & MYD08) are archived and can be acquired from the same distribution facility, the LAADS DAAC https://ladsweb.modaps.eosdis.nasa.gov

1.0.3. Definition of "Level"

A quick definition of the "Level" term for those not familiar. The "Level" terminology is used to denote broad categories of satellite data products. Level-0 (L0) denotes raw spectral channel counts, Level-1B (L1B) denotes calibrated and geolocated radiances, Level-2 (L2) denotes orbital-swath science products, typically organized into files with only several minutes of data, and finally Level-3 (L3) denotes global-gridded science products, most commonly compiled on longer time frames like daily or monthly.

1.0.4. Scope of this Document

This document describes the Continuity Atmosphere Level 3 (L3) CLDPROP (or Cloud Properties) products. Topics covered include computational approaches and scenarios, subsampling and gridding characteristics, caveats to be aware of, similarities and dis-similarities to the MODIS Standard L3 products, and finally a breakdown of the parameters and statistics computed in L3.

1.1. L3 CLDPROP File Characteristics

There are currently four L3 Continuity Atmosphere products (See Table 1) derived from three instrument/platform combinations (MODIS Aqua, VIIRS SNPP, & VIIRS NOAA20) and derived at two temporal periods (daily & monthly). L3 Daily Continuity Products are tagged D3, which is short for L3 Daily. L3 Monthly Continuity Products are tagged M3, which is short for L3 Monthly.

The acronym CLDPROP (used at the beginning of the filename in both L2 and L3) is short for Cloud Properties, which includes both Cloud Optical Property (COP) and Cloud Top Property (CTP) L2 parameters.

L3 Daily (D3) Continuity CLDPROP products are derived directly from the L2 Continuity CLDPROP Products. L3 Monthly (M3) Continuity CLDPROP products are derived directly from the L3 Daily (D3) Continuity products only. Monthly (M3) products never read L2 data, only the Daily (D3) products read L2 directly. See Table 1.

L2 Granule Input Product		L3 Daily Output Product		L3 Monthly Output Product
CLDPROP_**L2**_MODIS_Aqua	➡	CLDPROP_**D3**_MODIS_Aqua	➡	CLDPROP_**M3**_MODIS_Aqua
CLDPROP_**L2**_VIIRS_SNPP CLDPROP_**L2**_VIIRS_NOAA20	➡	CLDPROP_**D3**_VIIRS_SNPP CLDPROP_**D3**_VIIRS_NOAA20	➡	CLDPROP_**M3**_VIIRS_SNPP CLDPROP_**M3**_VIIRS_NOAA20

Table 1. CLDPROP File Acronyms and Processing Flow of L3 Products

1.1.1. File Format

One of the changes made in the newer Continuity Atmosphere Products (as compared with the older MODIS Standard Atmosphere Products), is the new Continuity Atmosphere products are in NetCDF4 format, instead of the older HDF4 format used for MODIS Standard products.

There are some differences in the how data contained within these files are organized when comparing NetCDF4 L3 Continuity format vs. the older HDF4 L3 MODIS Standard format -- the primary one being that L3 Continuity NetCDF4 files are organized into broad Groups (e.g. Cloud_Top_Pressure) -- and statistics are stored as Variables under that Group (e.g. Mean, Standard_Deviation, Pixel_Counts, etc.). In the HDF4 L3 MODIS Standard products, statistics were stored in individual (stand-alone) Scientific Data Sets (SDSs) where the parameter name and statistic type were combined in advance into a single structure

(Cloud_Top_Pressure_Mean).

1.1.2. Resolution

The statistics in L3 CLDPROP files are at 1×1° resolution on a rectangular lat-lon global map. This means that all L3 statistics have an array size of 360 columns by 180 rows (360x180), with each L3 grid cell representing 1 degree of latitude and longitude.

Each Level-2 atmospheric parameter is retrieved at a spatial resolution determined by the single field of view (FOV) of the key spectral bands of the instrument required to perform the retrieval. Resolutions of L2 CLDPROP science products are at 1×1 km for MODIS Aqua and 750x750 m for VIIRS SNPP & VIIRS NOAA20. L3 Atmospheric parameters are computed at 1×1° spatial resolution.

1.1.3. Filename Convention

Level-3 (L3) Continuity Atmosphere Product NetCDF4 files are named using a standardized convention as displayed below in Table 2. Note that for the sample NetCDF4 filename shown:

- The first part of the new standardized Product Prefix is the Product Type (CLDPROP).
- The second part is the Level (D3 for Daily or M3 for Monthly).
- The third part is the Instrument (MODIS or VIIRS).
- The fourth part is the Satellite Platform (Aqua, SNPP, or NOAA20).
- The DDD in the date denotes the Day of Year (001-366).
- All times are UTC time, not local time.

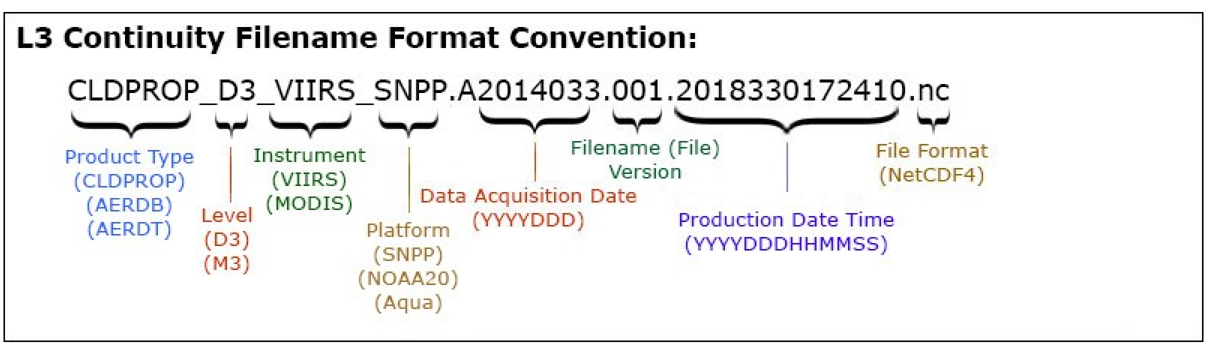


Table 2. The File Format Naming Convention for L3 CLDPROP files

1.1.4. Versioning: The relationship between Filename (File) Version and Data Version

There are two primary ways versions can be discussed: a filename (or file) version, which is part of the NetCDF4 filename (e.g. 001) shown in Table 2; and a data version, which is a more conventional method of versioning (e.g. v1.0), which is generally used in written or verbal communications by the Science Algorithm Teams and in publications. Note that there is a third version tag internal to CLDPROP files, where a *global attribute* called product_version is set. For Collection 011, the product_version is set to 1.1.0 and could be thought of as similar to the old Product Generation Executive (PGE) version used in MODIS Standard files. This third version tag is used to track the version of the algorithm software used to generate the files. The first two digits of the product_version typically matches the data version -- and the final digit in the product_version increments when a new algorithm version is delivered and integrated to make a minor bug fix or minor enhancement.

It should be noted that the first publicly released version of L3 CLDPROP, processed in late Summer 2019, is assigned data version v1.1, is tagged 011 in the filename (see filename version in Table 2), and the product_version is set to 1.1.0 (as a *global attribute* internal to the file).

This v1.1 or 011 versioning tag for L3 CLDPROP matches the version of the L2 CLDPROP input, which was reprocessed as v1.1 starting in August 2019. Note that the v1.1 L2 CLDPROP update fixes an issue with the optical properties thermodynamic phase that previously resulted in erroneous liquid-water cloud phase results. As a reminder, the initial (beta release) v1.0 L2 CLDPROP products were publicly released in LAADS (the distribution point for CLDPROP data) in April 2019. While the new v1.1 CLDPROP products were publicly released in August 2019.

A specific version of data generally stays "current" (is distributed) for anywhere from 6 months to sometimes several years. When reprocessing with an updated CLDPROP algorithm version is undertaken, the previous version of data often continues to be distributed while a new version is being processed and distributed. So in some instances, two versions of CLDPROP data will be in the public archive. Users should always attempt to acquire and use the latest version.

While most might think of versions typically incrementing by one (001 to 002) when reprocessing is undertaken -- versions can sometimes increment by *point one* (denoting a more minor update) which leads to unusual increments in the filename version: 001 to 011 (due to the unusual 3-digit filename version convention of the LAADS DAAC, the distribution point for CLDPROP data). The related (parallel) data version, used by the Science Algorithm Teams, will always follow a more logical (easier to interpret) pattern: v1.0 to v1.1 to v2.0.

During the processing of a particular version, an attempt is made to use the same science algorithm, sometimes known as the Product Generation Executive (PGE). However, occasionally several new PGE's (algorithm updates) are released during a particular data version to fix minor bugs or make improvements to the data. For bug fixes, if the bug is not serious, forward processing will continue with the new corrected PGE, while old previously processed data (which was produced with an older version algorithm (PGE)) are left in the archive.

When enough changes or improvements are made to a science algorithm, the entire data version, which for Standard MODIS was called a collection, is typically reprocessed and then tagged & distributed as a new version (for example, going from v1.0 (001) to v1.1 (011)). Preparation to go to a new version can be a major effort that can take anywhere from a few months to a year or more to prepare and complete.

Note that issues, anomalies, and problems in a particular version are outlined in the Data Issues section of the Atmosphere Imager website as they are discovered https://atmosphere-imager.gsfc.nasa.gov/continuity/issues

1.1.5. Start Date for the Continuity CLDPROP Products Data Record

As of Fall 2019, the start date for Continuity CLDPROP products (both L2 and L3) is year 2012 and day of year 061 (1 March 2012) -- and the data record continues to the present day.

1.1.6. Long term plans for Continuity CLDPROP Products

Our long-term plans are to process CLDPROP back to the beginning of the Aqua record (July 2002), however our initial releases are focused only on the EOS-SNPP overlap time period (March 2012-present) so that we can assess product continuity and work out any unexpected or unforeseen issues. Unfortunately, as of Fall 2019, there is no time-frame for when the pre-2012 processing will happen.

1.2. L3 CLDPROP File Metrics

1.2.1. Group (Parameter) and Variable (Statistic) Metrics

The current version (v1.1) of the L3 CLDPROP Continuity Atmosphere Global Product (both Daily and Monthly) contains 837 Variables (Statistics) that are computed for 128 Scientific Groups (Parameters) derived from Level-2 Continuity Atmosphere CLDPROP files.

All L3 statistics are sorted into 1×1° cells on an equal-angle global grid (see section 2.0). A number of statistical summaries are computed for each of these L3 parameters, depending on the parameter being considered.

Statistics for a given L2 parameter or measurement might include:

- Simple (Mean, Standard_Deviation, Pixel_Count, Sum, and Sum_Squares) statistics
- Parameters of log-normal distributions
- Fraction of pixels that satisfy some condition (e.g., liquid water clouds, ice clouds)
- Histograms of the sampled L2 pixels within each grid box
- Joint Histograms derived from comparing one science parameter to another, statistics may be computed for a subset that satisfies some condition. Joint Histograms of Uncertainly are also provided.

1.2.2. File Sizes for NetCDF4 Daily and Monthly files

For the current version (v1.0) of L3 CLDPROP Product Files, the Daily (D3) NetCDF4 file is a bit less than 500 MB in size, the Monthly (M3) NetCDF4 file is around 800 MB in size. These files used standard packing tools to reduce the file sizes as much as possible to aid users in downloading and storing data

1.3. L3 CLDPROP Definition of "Day": Time span of the Daily Product

The issue of how to define a *single day of data* in a Daily file is more complex than one might initially think; but before we delve into this topic, let's first review how L2 granules are time-stamped.

1.3.1. Time Stamping of L2 Files

L2 CLDPROP data granules (input to L3 Daily CLDPROP) are always time-stamped using Coordinated Universal Time. Coordinated Universal Time is International Atomic Time (TAI) with leap seconds added at irregular intervals to compensate for the Earth's slowing rotation. These added leap seconds allow Coordinated Universal Time (UTC) to track the mean solar time at the Royal Observatory, Greenwich (GMT).

Coordinated Universal Time is abbreviated UTC. The reason for this seemingly unusual abbreviation is the International Telecommunication Union wanted Coordinated Universal Time to have a single abbreviation for all languages. English speakers and French speakers each wanted the initials of their respective language terms to be used internationally: "CUT" for *coordinated universal time* in English, and "TUC" for *temps universel coordonné* in French. This resulted in the final compromise (which likely pleased no one) of using "UTC."

Each L2 Continuity MODIS granule (stored in a single NetCDF4 file) contains 5 minutes of data. Each L2 Continuity VIIRS granule (stored in a single NetCDF4 file) contains 6 minutes of data.

The time stamp (which is part of the L2 NetCDF4 file name) shows the start minute of the data collection time period. For example, a L2 MODIS Aqua granule (contained within a single

NetCDF4 file) might have a time stamp of 1430. This means the start time of data acquisition was 14:30:00 UTC and the end time was 14:34:59 UTC. The subsequent NetCDF4 granule would have a time stamp of 1435, which corresponds to an acquisition start time of 14:35:00 UTC.

1.3.2. Definition of "Day" for MODIS Standard Products (MOD08_D3)

In MODIS Standard L3, in Collection 5.1 and earlier, the method to define a "Day" was using a simple 0000 to 2400 UTC period. However, some users complained that this definition led to an unusual pattern of orbital gaps and overlaps (gaps and overlaps on alternating days) near the International Date Line for day, and near the Greenwich Meridian for night. Therefore, starting in Collection 6.0, the definition of "day" was adjusted such that L2 files with time stamps that extended outside of the 24 hour (0000 to 2400 UTC) day were utilized in order to potentially remedy this shortcoming.

In this correction, L2 data as much as 3 hours before the start of, or 3 hours after the end of, a UTC day is included. Then L3 longitudinal map boundaries (the International Dateline for day, and the Greenwich Meridian for night) were used to chop off unnecessary pieces of superfluous granules, making a cleaner more well-behaved boundary with no (or at least fewer) orbital gaps and overlaps. For more details and visuals on this method, refer to online documentation at: https://atmosphere-imager.gsfc.nasa.gov/Definition_of_Day_Four_Panel

This modification in the MODIS Standard Products for Collection 6 (and later) was termed the "*Definition of Day Correction for MODIS C6*"

Because of this correction, in the MODIS Standard Collection 6.0 and 6.1 data, one will rarely see large data gaps or data observed (at mid latitudes) nearly 24 hours apart being mixed together in the same geographic region.

Unfortunately, it was later discovered that this "Definition of Day Correction" technique that was implemented for MODIS Standard L3 data, left (in some very specific post-processing scenarios) a visible artifact around the daily global "seams" of the individual days, which were focused around the meridian where the day or night boundary ended or began. And further, it was found that this artifact did not get averaged out over long time period (annual) aggregations for those very specific cases. One SDS (Scientific Data Set) in particular (Cloud Fraction from Cloud Mask) appeared very sensitive to this issue. The specific scenario that was problematic was when combined Day+Night, and also combined platform (Aqua+Terra) data was merged, but only for Cloud Fraction from Cloud Mask (in the set of SDS's that were studied). It was theorized that the reason that cloud fractions appeared to be more susceptible to this issue, was cloud fractions included clear-data (pixels), while most other L3 SDS's do not, making the relative range of fraction data larger (spanning the full 0% to 100% valid range). Other post-processed MODIS Standard L3 SDS's that did not share this combination of (post-processed) aggregation characteristics: (i) Day+Night, (ii) Terra+Aqua, and (iii) Includes Clear Sky Pixels, did not appear to be affected (or at least not affected very significantly).

1.3.3. Definition of "Day" for Continuity Products (CLDPROP_D3)

To further muddy the water around the question of how we should define a *day of data* for Continuity Atmosphere L3 Products -- since we wanted to use a single technique or set of equations to define our *data day* for all instrument/platform combinations in the Continuity data stream, the unique (different) orbital geometry patterns and signatures of various (different) satellite platforms began to rear its head.

During some detailed analysis performed in our L3 research code (MARA) by Gala Wind, it was found that VIIRS/SNPP data had a radically different orbital geometry vs. MODIS/Aqua data over a daily timeframe -- and that using our old MODIS Standard *"Definition of Day Correction for MODIS C6"* on VIIRS data caused a larger more pronounced issue with data gaps and data overlaps that were not only bigger than those seen in MODIS data, but also moved around the globe in a choppy manner over time.

Because of these findings, we decided to revert back to the simpler and easier to describe method of defining a *day of data* in the Continuity Products, as a simple 0000 to 2400 UTC period. See Table 3. This simpler (more traditional) definition was also used in MODIS Standard L3 products prior to Collection 6.

Definition of Day	MODIS Std Atm ≤ Collection 5.1	MODIS Std Atm ≥ Collection 6.0	Continuity Atm ≥ Version 1
Standard Definition of Day L2 granule times included in a D3 file, span 00:00:00 to 23:59:59 exactly	√		√
Definition of Day Correction L2 granule times included in a D3 file, may start before 00:00:00 or end after 23:59:59		√	

Table 3. Users should be aware of the change in the *Definition of Day* in the Daily Products when comparing Collection 6.0 or later MODIS Standard L3 (MOD08_D3, MYD08_D3) with Continuity L3 (CLDPROP_D3). L2 Granules included in a MODIS Standard D3 Product with the *Definition of Day Correction* applied, may start up to 3 hours before 00:00:00 UTC or end 3 hours after 23:59:59 UTC and then be truncated using specific longitudinal boundaries (International Date Line or Greenwich Meridian) creating "cleaner" edges. A procedure similar to this turned out to be too unwieldy to define properly in L3 Continuity products due to data from multiple platforms with different orbital geometries being produced.

Whether or not there might be post-processing artifacts (that remain detectible even at longer-term time intervals) from this simpler *definition of day* used for L3 Continuity data (as was seen in some selected SDSs in L3 MODIS Standard data using the *Collection 6 definition of day correction*) has not been studied yet.

However, it is well known that this more traditional 00:00:00 to 23:59:59 *definition of day* in the Continuity D3 products will produce well-known and well-documented orbital gap and orbital overlap issues, near the beginning of day and end of day in the new Continuity Daily data stream. These orbital gap and orbital overlap issues were seen in MODIS Standard D3 data prior to Collection 6. See Figures 1 and 2.

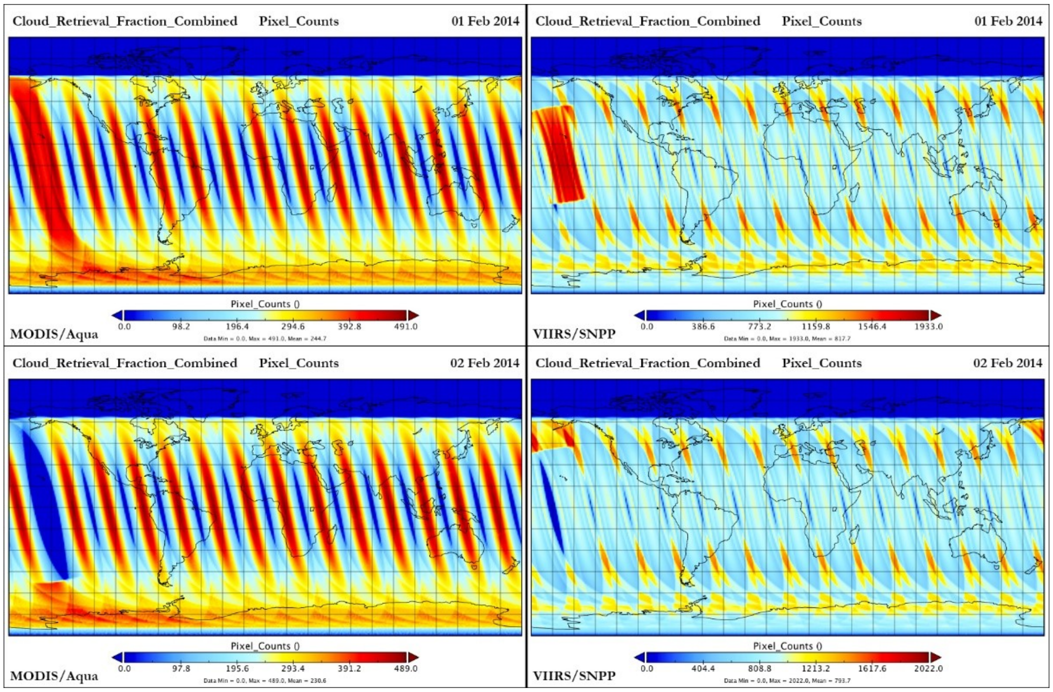


Figure 1. Pixel Count images for Cloud Retrieval Fraction Combined Cloud Phase (daytime only) that clearly show the orbit gap/overlap signature on successive days (as an asymmetrical orbit & count pattern) when using a 0000-2400 UTC rule for *Definition of Day*. Top panels are 01Feb2014, bottom panels are 02Feb2014 (the next day). Left panels are MODIS/Aqua, right panels are VIIRS/SNPP.

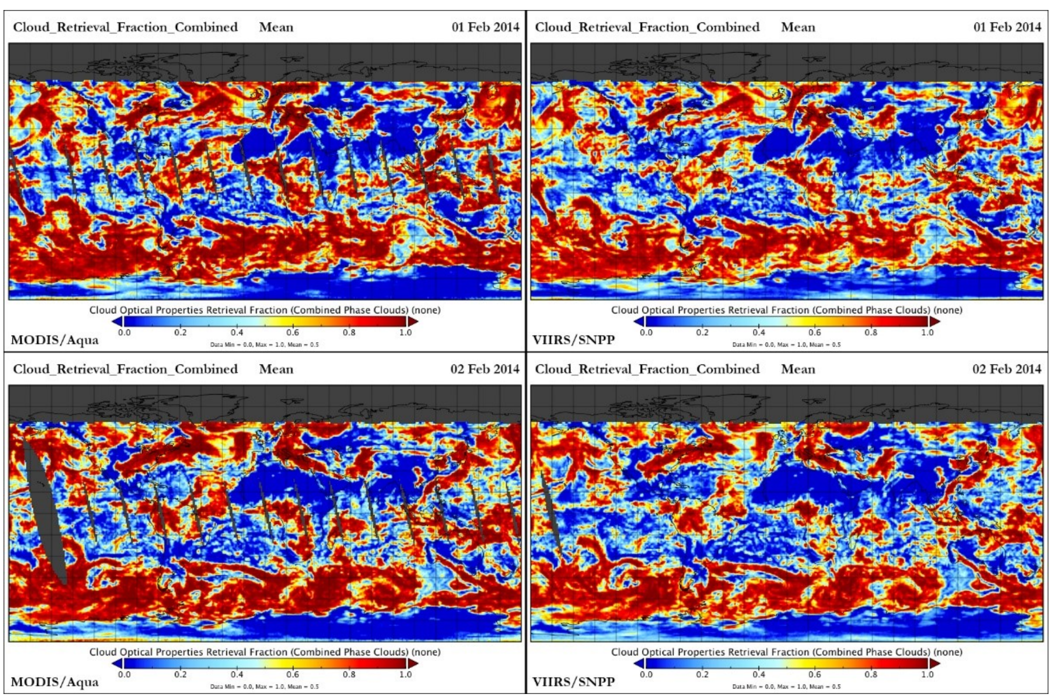


Figure 2. Even though the Pixel Counts (Figure 1) show an easy to detect signature, data users likely won't see any obvious signature in the Mean and Standard_Deviation statistics other than one or two asymmetries in the orbital gaps (shown as dark gray repeating stripes at mid latitudes).

2.0. Gridding

All Continuity Atmosphere L3 statistics are stored on an equal-angle latitude-longitude grid. The grid cells on this projection are 1×1° in size, which means the Continuity Atmosphere L3 output grid is always 360 pixels in width and 180 pixels in height. The left-most boundary of the grid (or map) is located at 180° W longitude, the exact center is the Greenwich Meridian 0°, and the right-most boundary of the grid (or map) is located at 180° E longitude. (See Figure 3).

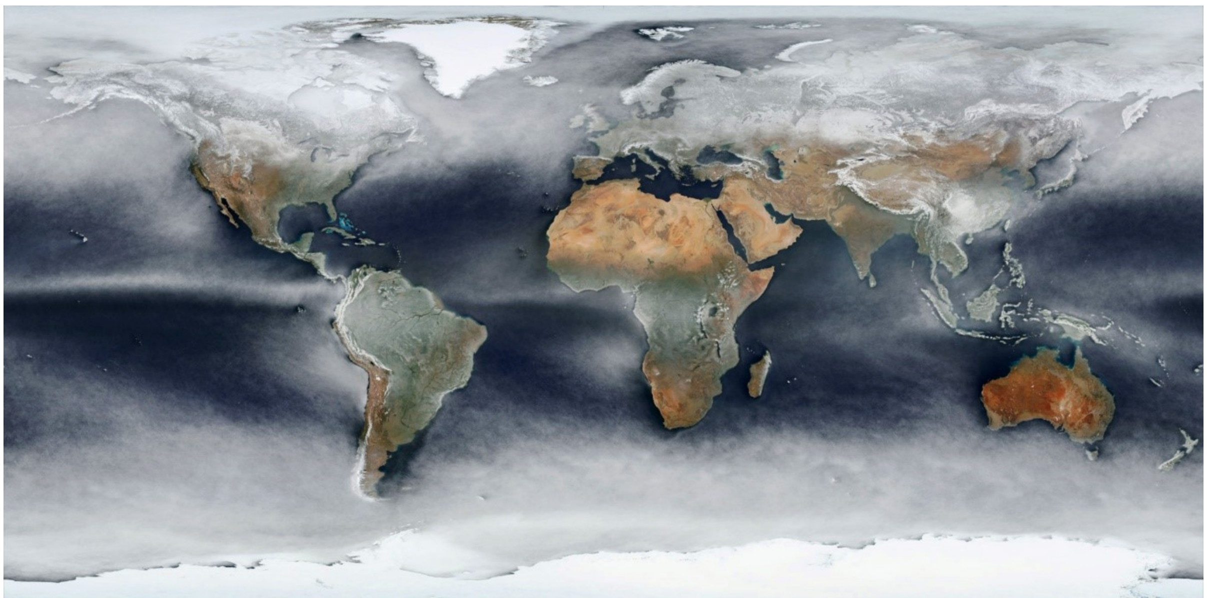


Figure 3. A sample 1x1 degree latitude-longitude rectangular grid. Displayed here is the result of collecting the daily RGB Corrected Reflectance images from the Suomi VIIRS sensor and calculating the per-pixel median over the full year of 2018. (Note that using the mean doesn't look as nice.)

L3 grid cells are indexed (0,0), since indexing starts at 0 in NetCDF4 files, at the upper left corner of the map and corresponds to a grid box with boundaries of 89° to 90°N latitude and 179° to 180°W longitude. L3 indexing increases as you move down and to the right on the map.

An example of a L3 Continuity Atmosphere parameter mapped on this standard 1×1° latitude-longitude grid is shown in Figure 4. Also shown in Figure 4 is a corresponding (matching) Corrected Reflectance image to compare science algorithm results with real world conditions (views).

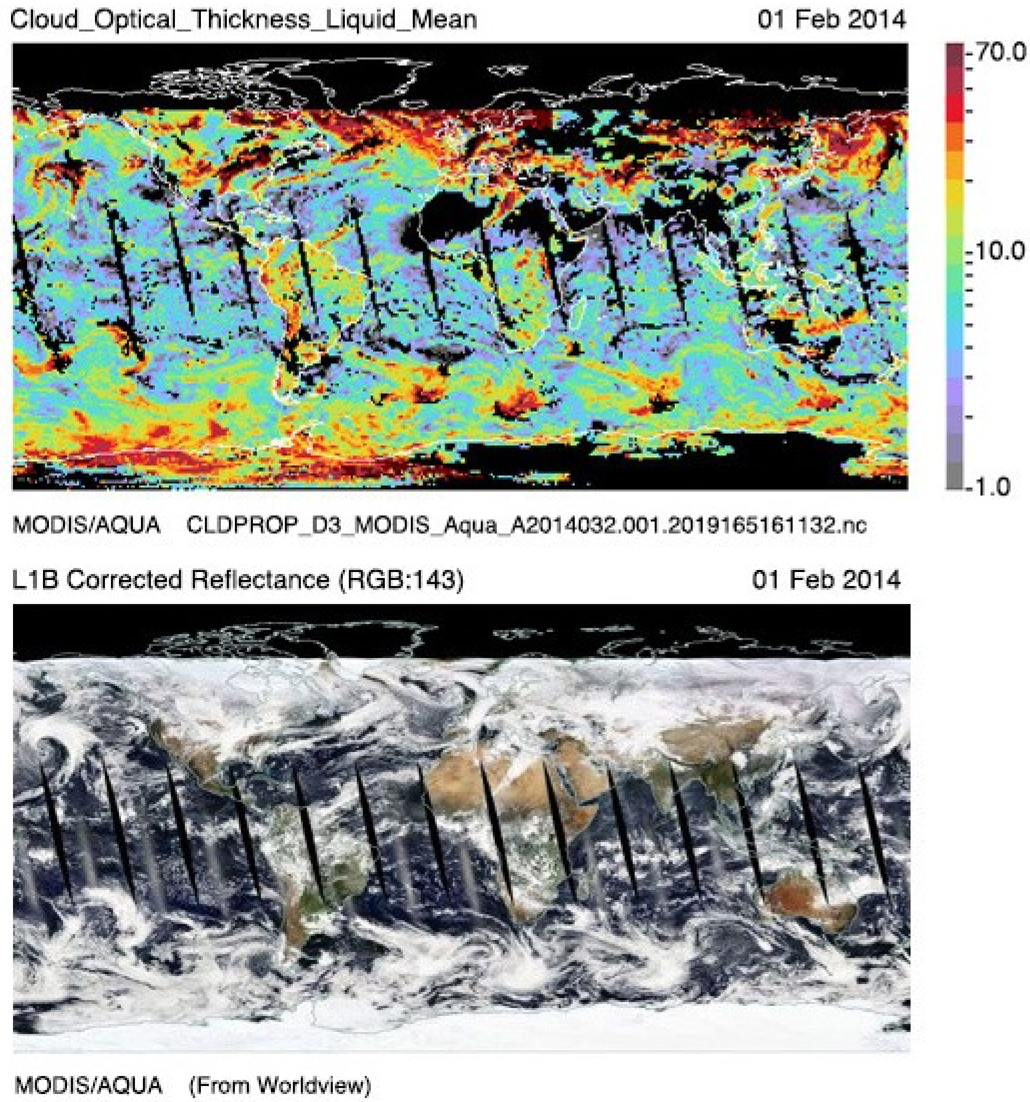


Figure 4. Top is a sample CLDPROP Daily (D3) Liquid Water Cloud Optical Thickness image shown in its native latitude-longitude projection format. Bottom is a corresponding (matching) L3 global image of Corrected L1B Radiances (RGB:143), shown for a real-world comparison.

The details of how L2 pixels get binned at L3 is important to understand, especially exactly at the boundaries of 1x1° grid cells. The assignment of L2 pixels (to a L3 grid cell) that fall exactly on a 1° L3 grid boundary is performed using the following convention: L2 pixels that fall exactly on the first whole degree boundary 90°N (+90.0) latitude and 180°W (-180.0) longitude are binned in the first L3 grid column and row (0,0). L2 pixels that fall exactly on the second whole degree boundary 89°N (+89.0) and 179°W (-179.0) are binned in second L3 grid column and row (1,1). The exception to this logic occurs in the last L3 grid row (89°S to 90°S), which contains both whole degree latitude boundary pixels (that fall on exactly-89.0 as well as -90.0). There is no exception for the last L3 grid column or longitude (179°E to 180°E) since +180.0 and -180.0 represent the same physical location (these L2 pixels are binned in the first L3 grid column).

An important property to note when considering L3 gridding occurs due to distortion in the latitude-longitude (rectangular) map projection as one moves poleward. The actual (real world) size of each 1° × 1° grid box physically shrinks when moving from the equator toward the pole due to the convergence of longitude lines on the globe (see Figure 5). At the equator each 1×1° grid cell is roughly 12,321 km^2 in size. At the pole each 1×1° grid cell is only 107 km^2 or less than 1/100th the size.

Figure 5. Convergence of longitude lines produces shrinking 1×1° rectangular grid cells toward the poles.

Please note that there is also a variation of pixel size in L2 (input) products due to viewing (scan angle) distortion. For example, in 1 km (nadir) resolution L2 data, the L2 pixels expand due to view-angle distortion when moving from nadir towards the limb (high scan angles) of an instrument scan (see Figures 6 and 7).

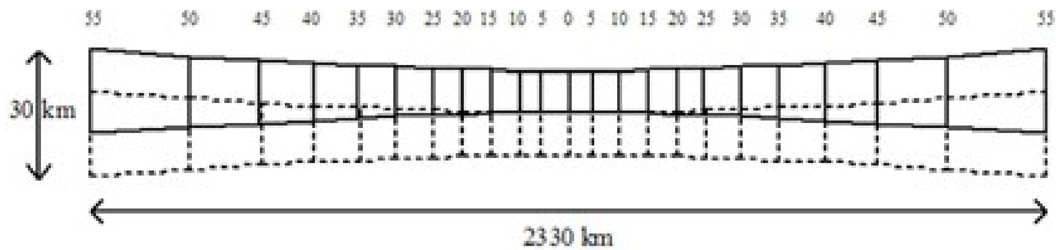
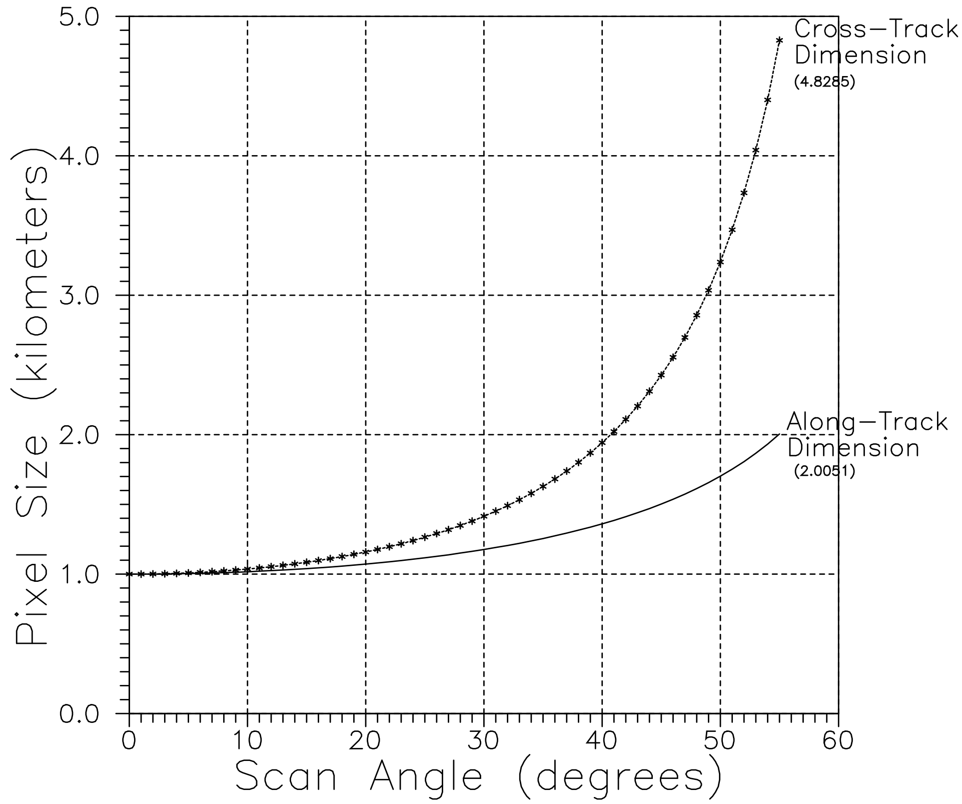


Figure 6. L2 pixel overlap due to scan width growth as a function of scan angle for the MODIS Instrument



....*..*..cross-track dimension

_______ along-track dimension

Figure 7. Estimated growth of a 1-km resolution L2 pixel as a function of scan angle for the MODIS Instrument.

This distortion of L2 input pixels means that there are fewer L2 pixels to average in the computation of L3 daily statistics for L3 1×1° grid boxes on a Daily (D3) product map that cover regions of high scan angles in the L2 orbital products, than for those that cover L2 orbital products computed closer to nadir view. For the Monthly (M3) products, this effect is averaged out and is mitigated.

Also note that this "growth" of the L2 pixel also causes some pixel (scene) overlap at high scan angles – meaning that the L2 pixels used to compute L3 daily statistics in these "orbit edge" regions are not as statistically independent as those computed with near-nadir-view pixels. So not only are there fewer L2 pixels to average at high MODIS scan angles, but they are less independent.

A third impact, these high scan-angle L2 pixels may be less reliable in general as they are viewed by the sensor through more atmosphere, which complicates the retrieval process.

A fourth impact is that they could have more inherent geolocation error depending on the local terrain.

Figure 8 shows the predicted orbital track (white lines) for the MODIS Aqua instrument for February 1, 2014. L3 gridding issues at the poles (due to very small (area-wise) L3 grid boxes) are exacerbated by MODIS orbital tracks that go no further north or south than roughly 82° – which means the pixels at the poles (90° latitude) are always viewed at higher scan angles. Also, there are 16 overlapping orbits near 82° latitude (each one roughly 98 minutes apart) that cause "time averaging" to occur for daily statistics computed poleward of about 77° (that is, in polar regions, statistics tend to be daily <u>average</u> statistics), in contrast to those at mid-latitudes (that typically can be pinned down to within 20 minutes of a MODIS instrument overpass).

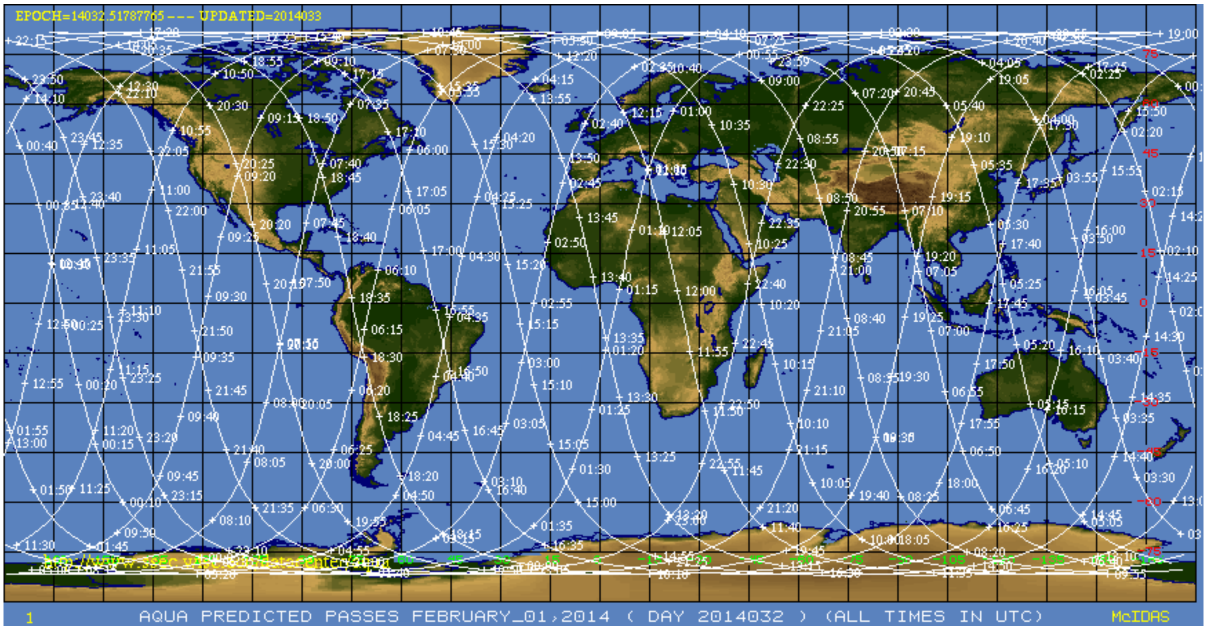


Figure 8. Predicted Aqua MODIS orbit tracks for a particular day (February 1, 2014).

In order to help visualize a typical distribution of L2 pixel counts that are used to compute L3 daily statistics, a sample daily pixel count image is shown in Figure 9. This figure shows the number of L2 pixels that typically go into the computation of statistics in each L3 1×1° grid cell for all (daytime only) Cloud Top Property statistics (1 km resolution at L2).

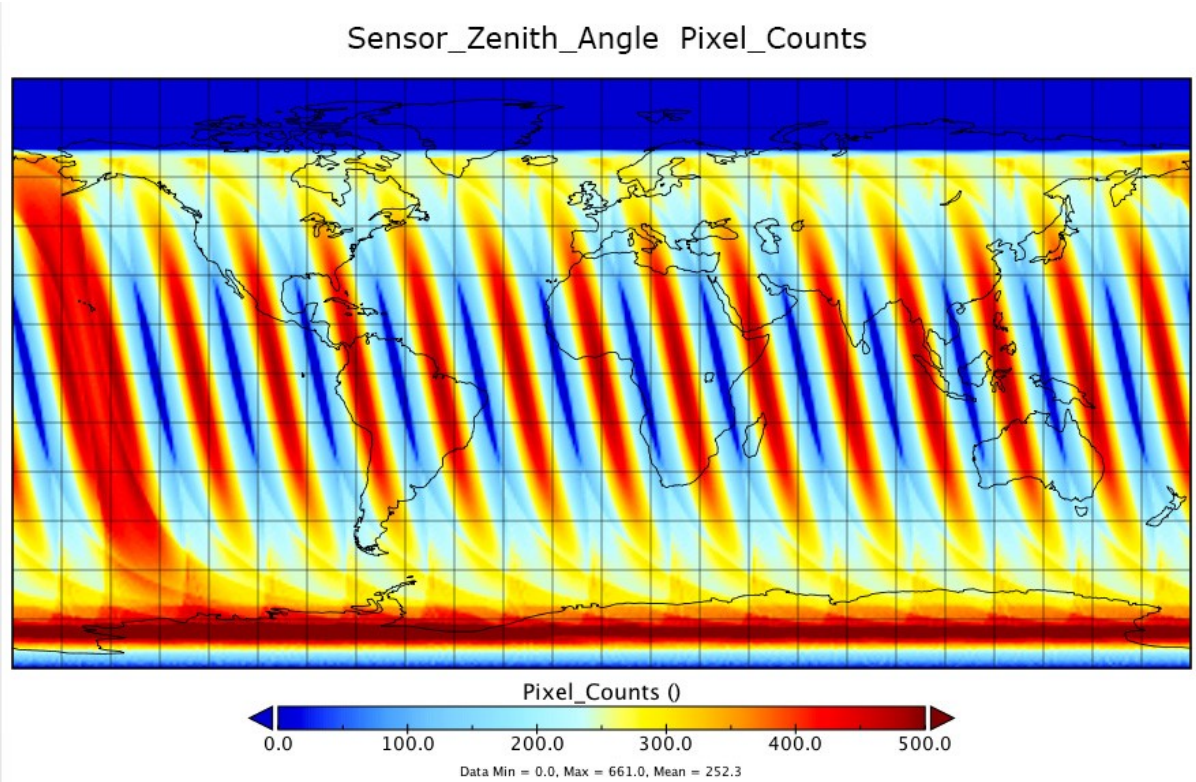


Figure 9. Typical global distribution of daily pixel counts (i.e., the number of L2 data pixels per 1° × 1° L3 grid cell) for 1x1 km resolution (sampled at 5km) L2 input products (where no aggregation is performed, limiting pixels) for MODIS Aqua. Note that this is a daytime (ascending node) only product. The date of this image is February 1, 2014 (same as the orbit track map shown in Figure 8). The overlapping orbit track just east of the International Date Line (see the extra wide red color in that region) shows very clearly the *definition of day* issue discussed in Section 1.3.

It is clear from Figure 9 that upwards of over 700 L2 sampled pixels were used to compute L3 statistics for this SDS near nadir (the bright red color at mid latitudes) -- but fewer than 15 L2 pixels were used near the edge of the scans (the mid-blue color at mid latitudes).

Note that the missing or orbital data gap regions on this daytime image are depicted by the dark blue color at the north polar region and repeating orbital gap regions at mid-latitudes, where pixel counts are 0.

Pixel counts for MODIS Aqua 1km input data sampled at 5 km typically range from 0 to 484 (22 × 22) sampled pixels. The number 22 in the previous sentence comes from 1 degree of latitude or longitude being roughly 111 km at the equator, so there are typically 22 five kilometer samples that span that distance.

However, one-degree L3 grid cell pixel counts can exceed these expected (nominal) maximum pixel count numbers where overlapping orbits and near-nadir-views intersect (typically around 82° north latitude in the Summer and 82° south latitude in the Winter). While the reduction of counts in the bottom few rows of latitudes (82°S to 90°S) in Figure 9 is due to count reduction from increasing L2 view-angles (that make the L2 pixels larger) and therefore fewer fall into a given (shrinking, due to Earth geometry) polar L3 1x1° grid cell, since one L2 pixel is only assigned to one L3 grid cell in our mapping system.

The pixel counts for L3 Continuity VIIRS data will be a bit larger (by about 25%) than for L3 Continuity MODIS/Aqua data due to the L2 input data being at 750m resolution for VIIRS, instead of 1km for MODIS.

So for the first and last few latitude bins (88° to 90° latitude), one has the dual drawback of (i) very small (area-wise) L3 grid cells containing small populations of relatively large input L2 pixels that overlap spatially (due to view-angle distortion) in a single orbital pass; and (ii) multiple orbital passes (up to 16 on a given day for MODIS) that take measurements of the region, which causes the L3 Daily data to be more representative of a daily average instead of a single overpass snapshot at the poles.

Users should note an important property of L3 gridding: in order to simplify the L3 operational production software, each L2 pixel is "located" or placed in the L3 grid cell where its center latitude/longitude falls within the L3 grid cell. In cases where a larger (view-angle distorted) L2 pixel actually covers (or intersects) more than one 1×1° L3 grid cell, (a situation that typically occurs at high L2 scan angles located over higher latitudes), the L2 pixel is still only assigned (placed) in the single L3 grid cell where the geolocated center point of the L2 pixel is located. Although this shortcoming is relatively minor in the operational L3 software due to the relatively large 1×1° L3 grid size and the much smaller L2 pixel size (750 m or 1km at nadir view), when the code is used in "research mode" to produce products at higher resolution (0.25° or 0.1° for example), it can produce unusual visual effects in the imagery where unnaturally appearing gaps are introduced between adjacent L2 pixels, as illustrated in Figure 10.

Finally note that most of these pixel count variation issues are mitigated in the Monthly (M3) product since the orbital gap positions shift from day to day, which allows data from subsequent days to fill in the previous day's gaps. This will tend to provide complete global coverage over these longer time periods.

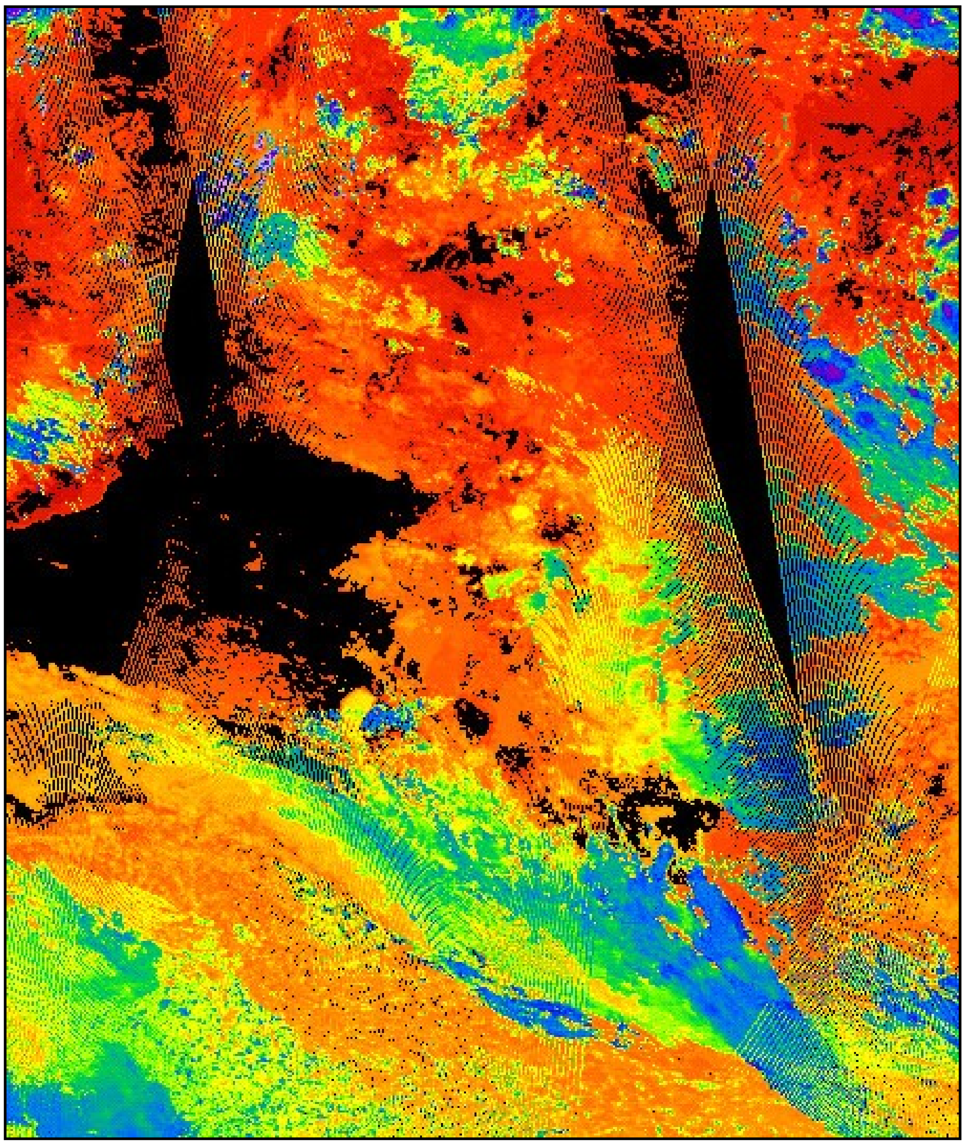


Figure 10. A section of a L3 Cloud Top Temperature image, produced for L3 research purposes at 0.1° × 0.1° resolution, clearly showing the pixel binning limitation (depicted by the moiré pattern visible at the edges of orbits) in the L3 code for grid meshes finer than 1° (the grid resolution currently implemented in operations).

3.0. Sampling

3.1 The Decision to Sample L2 data for L3 Computation

Continuity Atmosphere Level-2 (L2) CLDPROP Products always have data and geolocation arrays stored at 1km resolution for MODIS and 750m for VIIRS. Since the L3 grid size (1°) is so much larger than the L2 resolution (1km and 750m), sampling of L2 input data for computation of L3 statistics is always performed. The main reason for this is to make the L3 computation faster. In addition, it was found in a number of studies (early on) for MODIS that sampling 1km L2 data at 5km had little effect on computed L3 statistics, at the L3 operational grid resolutions of 1x1°.

3.2 Sampling Technique for Continuity MODIS

3.2.1. Sampling modification to avoid dead detectors for MODIS Aqua

A software modification was introduced in L3 MODIS Standard Collection 5 (and forward) products, which offset slightly the L2 data point sampled (in the 5x5 km L2 space) and was necessary to avoid dead Aqua detectors for some channels. This patch **only** impacted L3 data that were derived from **sampled** L2 input (that is, where 1km L2 data was sampled at 5km for L3 computations).

In MODIS Standard Collection 4 and earlier, 1km L2 products were sampled in the center grid of the 5x5 km region. It was thought the center grid would be the most representative of the entire 5x5.

When MODIS Aqua suffered a failure of detectors 3 and 8 in band 6 (1.64 μm) just before Collection 5 started, it became necessary to shift the sampled pixels to avoid those dead detectors.

The choice of which alternate pair of detectors to pick [(1 & 6), (2 & 7), (4 & 9), or (5 & 10)] was made to both minimize errors in geolocation as well as inherent detector errors. It turned out, after some study, that detectors 4 and 9 had the dual benefit of: (i) being immediately adjacent to the 5km geolocation pixel so only a 1 km geolocation error was introduced, and (ii) both detectors 4 and 9 were well-behaved and had small residual errors when compared to averages taken over the entire 5 × 5 km area (Oreopoulos 2005). See Figure 11.

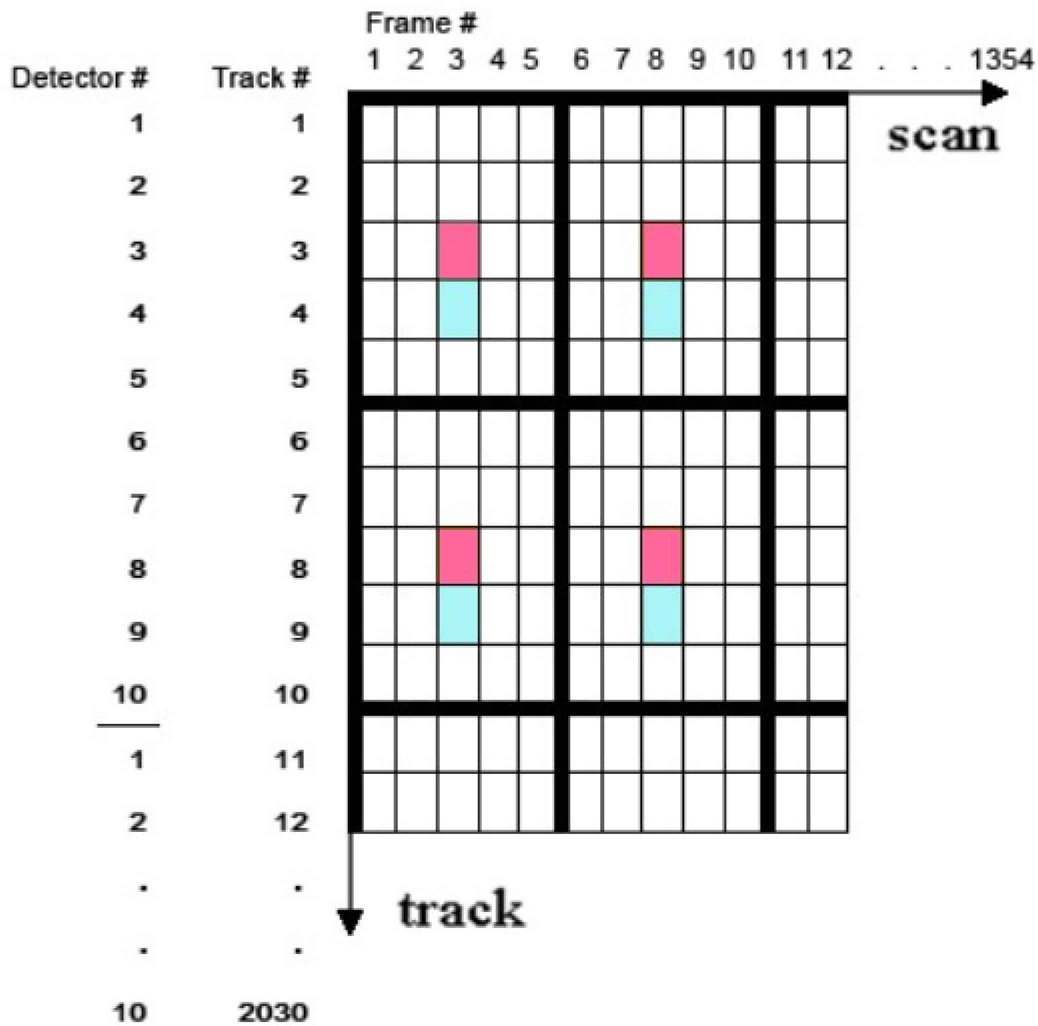


Figure 11. A shift in the L2 "sampling pixel" for L2 input products sampled at 5km was implemented to prevent dead detectors from causing missing L3 data. The pink color is where L3 MODIS Collection 4 sampled at the center of the 5 × 5 (detector 3, frame 3). The blue color is where L3 MODIS Collection 5 and later sampled (detector 4, frame 3) slightly off center of the 5 × 5 grid box. In other words, for MODIS Collection 4 and earlier, L2 pixels from detectors 3 & 8 were sampled. For MODIS Collection 5 and later, L2 pixels from detectors 4 & 9 were sampled.

Even though the change in start detector (from the 3rd to the 4th) was prompted by the failure of Aqua MODIS detectors 3 and 8 in band 6 (1.64 µm), the change was extended to Terra data as well after a study showed that Terra detector-pairs 4 and 9 provided the most representative results over a 5 km grid cell (Oreopoulos 2005) and it was further thought that matching the logic between Terra and Aqua versions of the L3 software was prudent and simplified L3 processing.

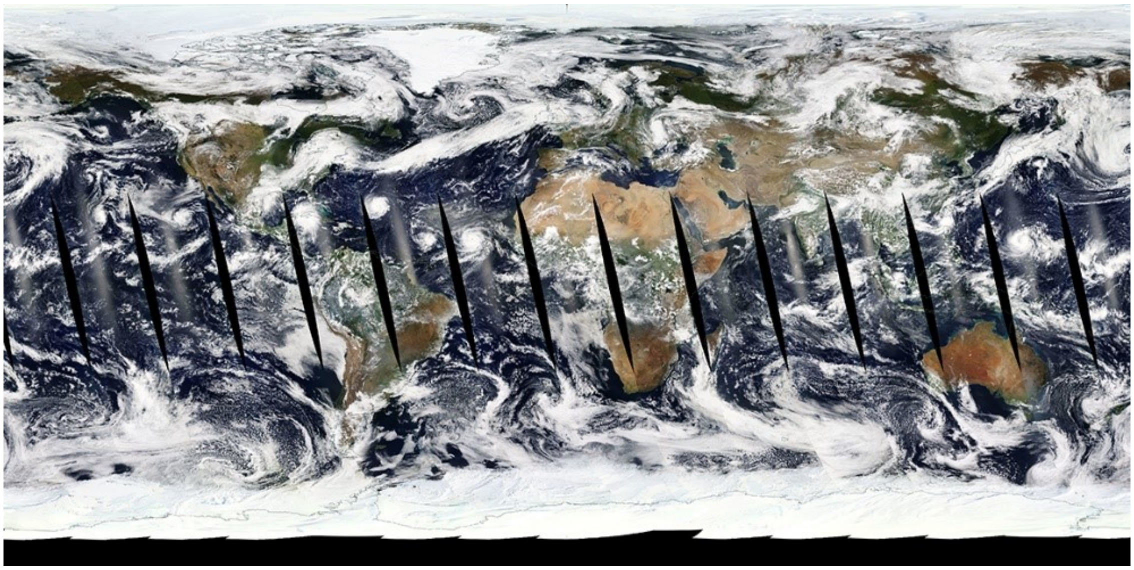
Therefore, for Continuity L3 Daily MODIS Aqua (CLDPROP_D3_MODIS_Aqua), it was necessary to match the sampling technique used in MODIS Standard L3 Daily MODIS Aqua (MYD08_D3) to (once again) avoid dead MODIS Aqua detectors as previously discussed. See the blue squares in Figure 11 showing detectors 4 and 9 being sampled.

3.3. Sampling Technique for Continuity VIIRS

For Continuity Atmosphere L3 VIIRS data, a radically new sampling method had to be implemented, but first let's review properties of the VIIRS L2 data.

VIIRS represents an advancement over MODIS in several respects. For instance, with a sensor scan angle range of ±56.28°, VIIRS views a 3060 km wide swath on the ground at its nominal altitude of 834 km, allowing for complete daily global coverage free of gaps. MODIS, on the other hand, has gaps between orbital swaths over the tropics, as it only views a 2330 km wide swath (±55° sensor scan angle range at 705 km altitude).

Figure 12 shows example global RGB imagery from (a) MODIS Aqua and (b) VIIRS SNPP from 10 September 2018. Note the lack of orbital gaps in the VIIRS SNPP image.



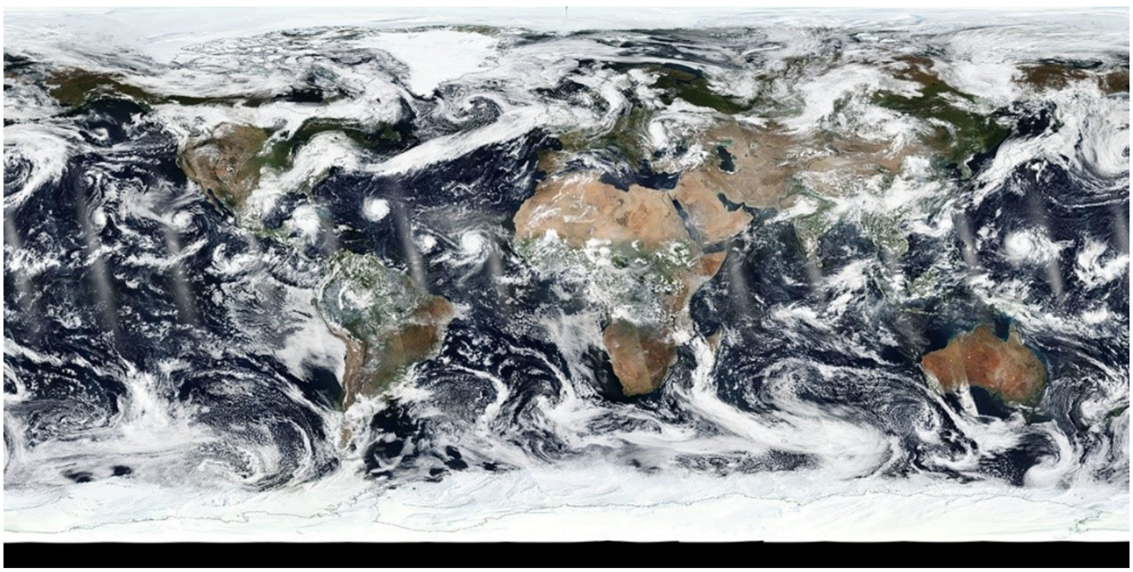


Figure 12. True color corrected reflectance (RGB:143) from September 10,, 2018. (a) MODIS Aqua. (b) VIIRS SNPP. The vertical black strips over the tropics in the Aqua-MODIS image (top) are the gaps between MODIS swaths from successive orbits. Note that the VIIRS image does not have these orbital gaps due to its wider swath. Images courtesy of NASA Worldview.

Moreover, while the 750 m nadir pixel size of the VIIRS M-bands is not substantially different from the MODIS 1 km nadir pixel size, VIIRS uniquely employs an on-board detector aggregation scheme that limits along-scan (across-track) pixel growth towards the swath edge. The 16 VIIRS M-band detectors are rectangular with a native footprint size at nadir of 250 m along scan (width) by 750 m along track (length). To achieve the 750 m nadir resolution of the

M-band L1B data, three along-scan detectors are aggregated for observations with sensor scan angles less than 31.72°, two detectors are aggregated for scan angles between 31.72° and 44.86°, and no aggregation is performed beyond 44.86° (see the sample aggregation zones in Figure 13, green text). Thus along-scan pixel width increases roughly only to 1.625 km at scan edge, comparable to the along-track pixel length growth; note that no along-track detector aggregation is performed.

The pixel growth (represented as horizontal sampling interval) in the along-scan and along-track directions is shown by the blue lines in Figure 13. Because the detector aggregation occurs on-board, the native detector data is discarded and only the aggregated data are downlinked. Further information regarding the on-board detector aggregation of the VIIRS M-bands can be found in *Section 2.1.1* of the *NOAA VIIRS Sensor Data Record (SDR) User's Guide* [*Cao et al.*, 2013].

MODIS is not designed to allow for such a detector aggregation scheme for all 1 km spectral channels. While channels 1-2 (0.66, 0.86 μm) and 3-7 (0.47, 0.55, 1.24, 1.64, 2.13 μm) are aggregated during L1B processing to 1 km (nadir) pixels from detectors having native nadir resolutions of 250 m and 500 m, respectively, L1B pixel sizes grow from the nominal 1 km at nadir to more than 2×4.9 km at scan edge [*Justice et al.*, 2011].

These differences in sensor swath geometry between MODIS and VIIRS can have profound impacts on the continuity of the cloud products derived from each. The wider swath of VIIRS allows for greater sampling at all latitudes, removing orbital gaps in the tropics while increasing swath overlap at higher latitudes. However, known view-angle-dependent biases, such as artificially increasing cloud fraction towards scan edge or the increased likelihood of viewing the sides of clouds (with implications on cloud top, optical, and microphysical retrievals), are likely larger in these additional VIIRS pixels. Furthermore, the limited pixel size growth of the VIIRS M-bands towards the edge of scan also reduces the impact of sub-pixel cloud heterogeneity and 3D effects that increase as pixel size grows and that have been shown to significantly impact the MODIS cloud optical/microphysical property retrievals under various conditions [e.g., *Zhang and Platnick*, 2011; *Zhang et al.*, 2012; *Cho et al.*, 2015].

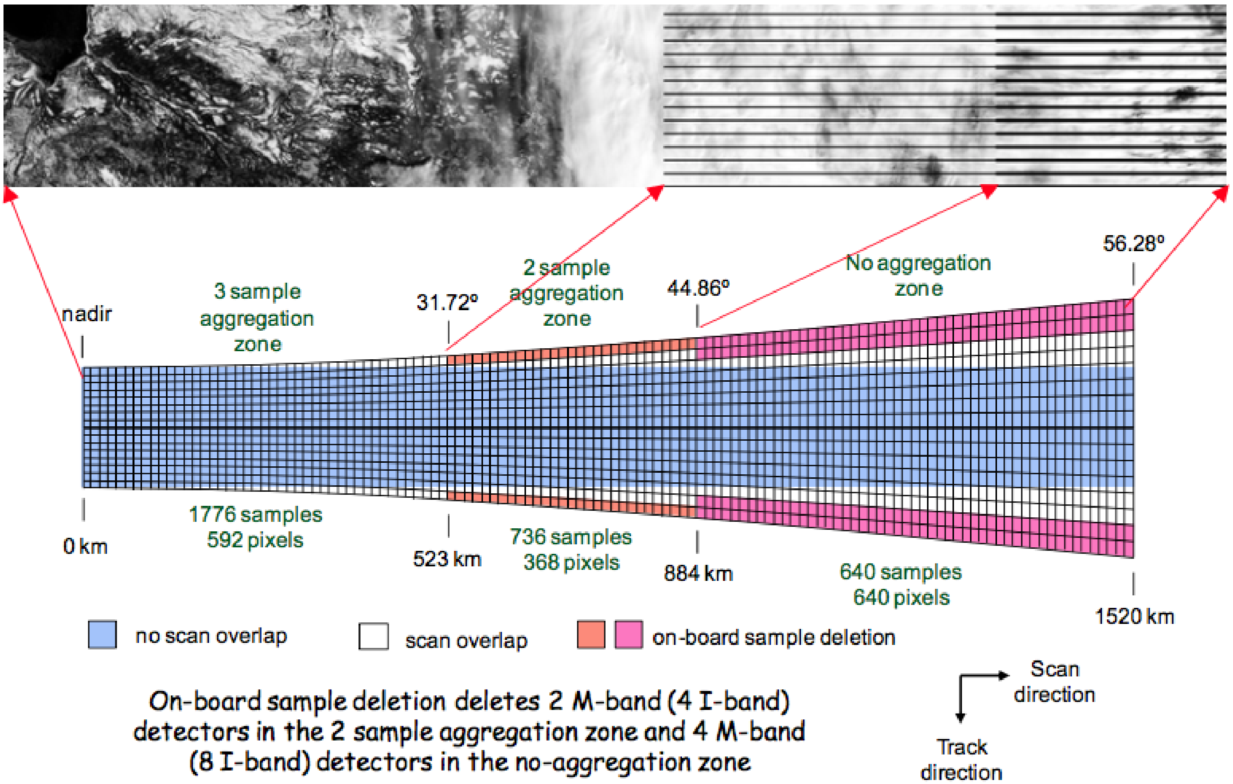


Figure 13. Illustration of VIIRS on-board along-scan detector aggregation zones (green text) and bow-tie pixel deletion. Figure obtained from the *NOAA VIIRS SDR User's Guide* [*Cao et al.*, 2013].

That said, the lack of direct sub-pixel information on VIIRS, available on MODIS from its 250 m VIS/NIR channels, limits the ability to identify and provide useful QA information (via sub-pixel heterogeneity indices, partially cloudy Clear Sky Restoral tests, etc.) on VIIRS pixels for which sub-pixel heterogeneity may nevertheless be impactful. It is possible that the VIIRS 375 m I-band (imaging) channels have the potential to provide useful sub-pixel information for the M-bands. However, these channels are not inherently co-located with the M-bands and, because they are coarser than the 250 m MODIS channels and do not map into the M-band 750 m pixels in the same way as the 250 m channels map into the MODIS 1 km pixels, they cannot provide the same level of information on heterogeneity. Further investigation is needed to determine the efficacy of the I-bands for assessing M-band sub-pixel heterogeneity.

Due to these many factors described, an optimal sampling technique for VIIRS data was devised and is shown in Figure 14.

The orange-colored grids in Figure 14 represent the L2 750m grids that are being sampled in L3. The red-colored grids are (regularly) sampled grids that are later set to fill-data – this was done to remove the lower quality data that is collected from detector 16 (the last detector) from getting into the L3 statistics. (Actually the data from detectors 1, 2, 15, and 16 are all of lower quality, and are hence excluded in this sampling technique.)

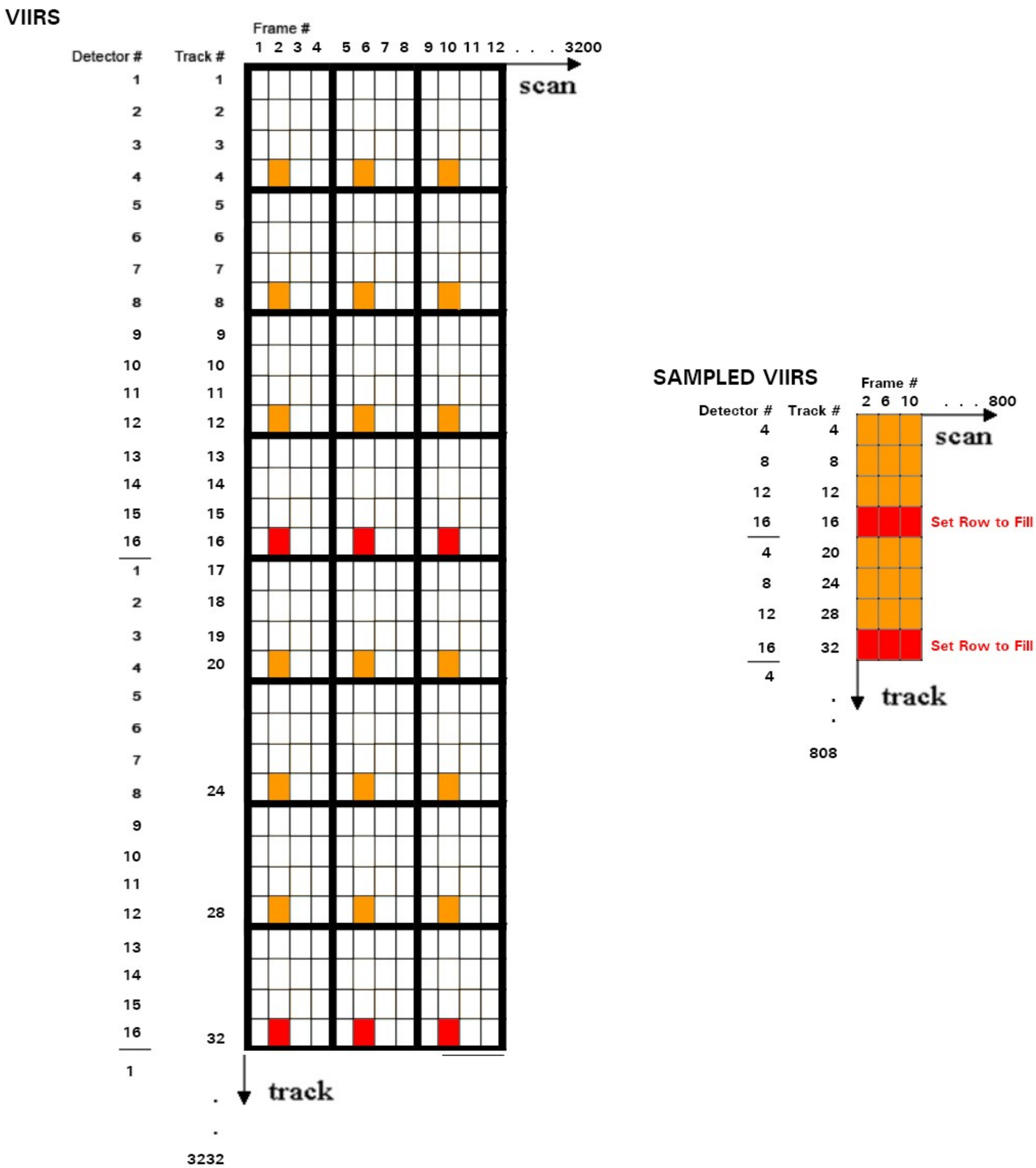


Figure 14. Illustration of the Sampling Technique used on L2 750m VIIRS data when computing L3 statistics. The orange grids are the sampled grids that are used in L3. The red grids are (regularly) sampled grids that are later set to fill-value in the L3 code, so that lower quality data (from VIIRS detector 16) is not aggregated into L3.

3.4. Summary of Sampling Difference between MODIS & VIIRS

To summarize, Continuity Atmosphere MODIS Aqua data (L2 resolution 1km) is sampled every 5km for L3. The start position for sampling is slightly offset from the center of the 5x5 km grid and instead shifted one detector position (1km) to detector 4, frame 3, in order to avoid dead detectors. So for MODIS Aqua, the detectors sampled are 4 and 9. (Note that there are 10 detectors in MODIS.) See Figure 15, left.

Continuity Atmosphere VIIRS data (L2 resolution 750m) is sampled every 3km for L3. Since there is no true middle frame in a 3x3 km grid, frame 2 was arbitrarily chosen as the start position. For VIIRS, the detectors sampled are 4, 8, and 12 (detector 16 is skipped due to lower quality data). (Note that there are 16 detectors in VIIRS.) See Figure 15, right.

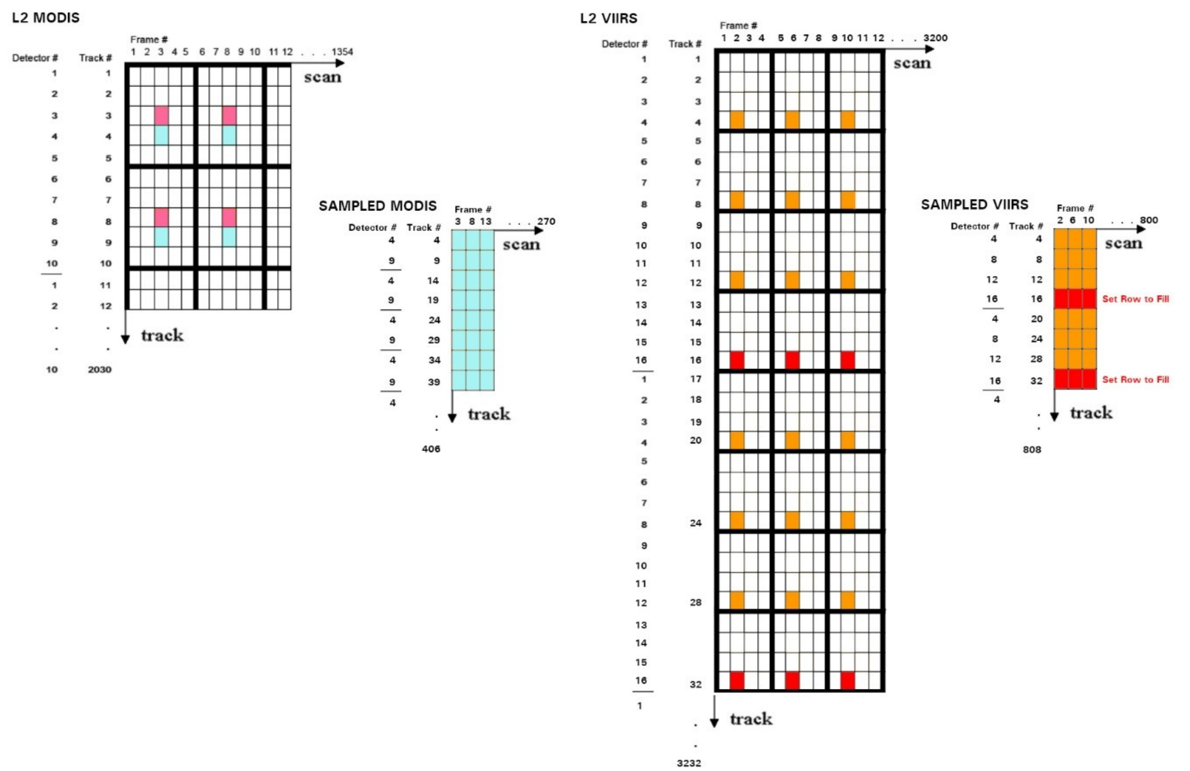


Figure 15. A rehash of earlier Sampling figures, (Figures 11 and 14), but now shown side by side. On the left is the MODIS Sampling method, where the blue-colored L2 pixels are sampled in L3. On the right is the VIIRS Sampling method, where the orange-colored L2 pixels are sampled in L3. Red pixels are set to fill-value and not used.

4.0. Computation of L3 Daily Statistics

4.1. Aggregation of Statistics

All Atmosphere L3 products (Daily (D3) and Monthly (M3)) make use of Aggregation capabilities. Aggregation information is typically based upon L2 QA bit flag arrays.

For some parameters, it is useful to aggregate results based on a physical characteristic of the parameter or of the scene. Aggregation refers to the ability to separate L2 input pixel information into various scientifically relevant categories such as liquid water clouds only, ice clouds only, daytime only, nighttime only, etc. These aggregations utilize L2 runtime QA flags that are designed to convey information on retrieval processing path, input data source, and scene characteristics of the physical parameters retrieved.

In addition, this broad group of flags also includes Cloud Mask flags (derived at 1 × 1 km resolution) to determine cloudy/clear or day/night scene characteristics.

Aggregated L3 statistics are often identified by a suffix to the Group (Parameter) name such as "_Liquid" or "_Night". Table 4 lists the various aggregations that occur in L3 CLDPROP.

Product Family	Aggregation Property
Cloud Top Properties	Day, Night
Cloud Optical Properties	Liquid Water, Ice, Undetermined, Combined Phase Clouds

Table 4. Aggregations that are performed in L3 CLDPROP.

Additional details and documentation about each Group (Parameter) are always provided in the local attribute "long_name" attached to each Group within the NetCDF4 file.

An interesting observation to note is that aggregations of L3 statistics are performed in Yori through the use of true/false (T/F) Masks that are defined in the Pre-Yori code and triggered by particular settings in the YAML (Yet Another Markup Language) Configuration File during processing. Multiple Masks may be applied to Statistics in any Group (Parameter).

The Masks which are currently defined in the Yori/YAML code are:

- Mask_Day: Daytime pixels based on the day/night flag
- Mask_Night: Nighttime pixels based on the day/night flag
- Mask_DayNight: Combined Day+Night pixels based on the day/night flag
- Mask_VZA_65p5: View zenith angle ≤ 65.5° (so VIIRS matches MODIS)
- Mask_CloudMaskDetermined: Cloud mask determined flag
- Mask_Liquid_Water_Phase_Clouds: Liquid water phase cloud retrievals
- Mask_Ice_Phase_Clouds: Ice phase cloud retrievals
- Mask_Undetermined_Phase_Clouds: Undetermined phase cloud retrievals
- Mask_Combined_Phase_Clouds: Combined phase cloud retrievals
- Mask_CSR0: Clear sky restoral flag set to 0
- Mask_CSR13: Clear sky restoral flag set to 1 or 3
- Mask_CSR2: Clear sky restoral flag set to 2
- Mask_Valid_Range_CER: Cloud Effective Radius ≥ 4.0
- Mask_Valid_Range_CERPCL: Partly Cloudy (PCL) Cloud Effective Radius ≥ 4.0

4.2. Types of Statistics computed

4.2.1. L3 Statistics Computed by Yori (the L3 Processing System)

Yori is the system/package that is used to process L3 Continuity Atmosphere Data. A total of 7 general types of statistics are computed in the Continuity Atmosphere L3 products within the Yori Processing System for each 1x1° grid cell. These seven statistics shown below are always found as individual Variables (tagged exactly as shown in the bullets below) under specific Groups within the NetCDF4 file. The Statistics are:

- Mean = the mean of the sampled L2 pixels in each L3 grid
- Standard_Deviation = the standard devidation of the sampled L2 pixels in each L3 grid
- Pixel_Counts = the counts of the sampled L2 pixels in each L3 grid

- Sum = the sum of the values of the L2 pixels in each L3 grid
- Sum_Squares = the sum of the squares of the values of the L2 pixels in each L3 grid
- Histogram_Counts = 1D marginal histogram counts of binned values of the L2 pixels
- JHisto_vs_xxx (where xxx is a secondary Parameter name) = 2D joint histogram counts of binned values of one set of L2 pixels vs. another set of L2 pixels of a different parameter

Note that in the Monthly CLDPROP file (product) the Mean is always pixel-count weighted, since it's based on L2 values stored as Sum and Pixel_Counts. It is not an unweighted Mean of the Daily Means. Likewise for Standard_Deviation, it's the standard deviation of the L2 input pixels.

4.2.2. Details of the Math Behind Yori *(Section 4.2.2.is from documentation on Yori L3 Gridding Tools)*

Since Yori can aggregate files that have already been aggregated (e.g., using 30 daily files to create a monthly product), it is important to clarify how the aggregation is performed and how the quantities stored in the files are computed. In this section we go through the details of the Yori aggregation phase where statistics are computed, starting from the trivial quantities and then working our way up from there.

4.2.2.1. Computation of Sum, Sum_Squares, and Pixel_Counts

Let's first briefly introduce how sums and sums of squares are computed during the L3 gridding phase. Although these definitions should be fairly obvious, they will be helpful as things progress in the following section.

For any given variable, the **sum** (Sum) represents the sum of its values v_j within a grid cell c and is computed as:

$$s_c = \sum_j v_j \qquad (1)$$

where the subscript j is the j-th pixel and v_j is the value of the quantity under consideration for that pixel j. The summation is performed over all the valid pixels, that is, all those pixels that aren't filtered out via masking in L3.

Similar to eq. (1) we can also compute the **sum of squares** (Sum_Squares), that is, the sum of the squared values of all the valid pixels inside a grid cell:

$$ss_c = \sum_j v_j^2 \qquad (2)$$

where the subscript j denotes the j-th pixel and v_j is the value of the quantity under consideration for that pixel.

The **number of points** (Pixel_Counts) at the L3 gridding stage is simply the count of the number of valid pixels n for any given grid cell c.

During the aggregation phase, the quantities introduced in the previous paragraphs are summed in order to compute what will be stored in the aggregated files. Hence, the aggregated **sum** (Sum) **is** derived as:

$$S_c = \sum_i s_{i,c} \qquad (3)$$

where the subscripts i and c represent the i-th file and the c-th grid cell respectively and S_c is the total sum for the cell c. Likewise, the aggregated **sum of squares** (Sum_Squares) SS_c is computed by just replacing $s_{i,c}$ with $ss_{i,c}$ in eq.(3):

$$SS_c = \sum_i ss_{i,c} \qquad (4)$$

Finally, the **number of points** (Pixel_Counts) for any given grid cell c is:

$$N_c = \sum_i n_{i,c} \qquad (5)$$

where, once again, the subscripts i and c indicate the i-th file and the c-th grid cell respectively, so that n is the number of points of the cell c for the file i and N_c is the total number of points for the same cell c.

4.2.2.2. Computation of Mean and Standard_Deviation

In this section we will explain how the mean (Mean) and standard deviation (Standard_Deviation) are computed during the aggregation and computation process. In the following the subscript c will be omitted for sake of simplicity but, unless otherwise stated, all quantities refer to a single grid cell.

The **mean** (Mean) M **of a** quantity is computed as:

$$M = \frac{\sum_i s_i}{\sum_i n_i} = \frac{S}{N} \qquad (6)$$

where the subscript i indicates the i-th file, while S and N are the sum and number of points respectively, introduced earlier in eqs. (1) and (5).

The **standard deviation** (Standard_Deviation) is derived from:

$$\sqrt{\frac{\sum_i ss_i}{\sum_i n_i} - \left(\frac{\sum_i s_i}{\sum_i n_i}\right)^2} \qquad (7)$$

where, again, i denotes the i-file and s_i, ss_i and n_i are sum, sum of squares and number of points described previously in eqs. (1), (2), and (5), respectively.

By saving sum, sum of squares, and number of points at every stage, and using eqs. (6) and (7), it is possible to correctly compute mean and standard deviation of all the elements within a grid cell without the need to also store all those values (in case further aggregation is required at a later stage).

For instance, this allows deriving monthly aggregations from daily data, which wouldn't be possible if the mean and standard deviation were computed directly from the values provided in the input files.

4.2.3. L3 Statistics computed by manual set-up in the Pre-Yori Step

Some desired L3 statistics were not directly computable by Yori (such as Fractions or Log Statistics). Fortunately, a part of the L3 Yori Processing System is a step called Pre-Yori, where L2 files are "massaged" into a format that can be read by the packaged (canned) routines of Yori (which are mostly fixed and unchanging). Because this Pre-Yori step exists, Science Algorithm Developers have the opportunity to create "set up" arrays, which can be used by the relatively basic Yori system to create more interesting and useful statistics. So for the CLDPROP L3 product, the Pre-Yori step was utilized to pre-process or set-up new L2 intermediate arrays, which could then be used by Yori to produce both Fraction (Cloud Fraction) and Log statistics.

4.2.3.1. Cloud Fraction from Cloud Mask

A number of different "flavors" of cloud fractions with different meanings and properties are included in the L3 CLDPROP Product.

The L3 cloud fraction that seems to garner the most interest from L3 Atmosphere data users is cloud fraction derived directly from the L2 cloud mask flags (from the CLDMSK product). Note that these cloud mask flags are duplicated in the L2 Cloud Properties (CLDPROP) product.

In the L3 CLDPROP product, the following aggregations of Cloud Fraction (from Cloud Mask) are available in the following L3 Groups (or Parameters):

- Cloud_Fraction
- Cloud_Fraction_Day
- Cloud_Fraction_Night

The first parameter listed above contains both day and night retrievals, the second parameter contains daytime-only retrievals (Solar Zenith Angle (SZA) ≤ 85°), and the third parameter contains nighttime-only retrievals. Note that the daytime cutoff for Cloud Mask (SZA ≤ 85°) is less strict than for Cloud Top or Cloud Optical Properties (SZA ≤ 80°).

Since the Yori Processing System was not designed to be able to compute fraction statistics directly, in order to compute Cloud Fraction (from Cloud Mask) using Yori, an intermediate L2 array called *Cloud_Mask_Cloudiness* is created in the Pre-Yori step of L3 processing.

This intermediate array is basically an array filled with 1s (True) and 0s (False). The 1s represent L2 pixels that are true (or cloudy) for the computation of the particular cloud fraction. The 0's represent L2 pixels that are false (because they were deemed clear or did not meet some other specified criteria).

To compute these 1s and 0s in the intermediate array, two L2 QA flags are read from the Cloud_Mask QA array in L2 CLDPROP. The two L2 QA flags are: the *Cloud Mask Status Flag* and the *Cloud Mask Cloudiness Flag* (see Table 5).

L2 QA Flag	Flag Value	Meaning
Cloud Mask Status Flag	0 1	Undetermined Determined
Cloud Mask Cloudiness Flag	0 1 2 3	Confident Cloudy (or Fill if Status Flag = 0) Probably Cloudy Probably Clear Confident Clear

Table 5. The two key L2 Cloud Mask Flags used to compute the intermediate Pre-Yori array *Cloud_Mask_Cloudiness*; and finally in the final L3 processing step, the Cloud_Fraction parameter in the L3 CLDPROP product.

To properly set the 1s and 0s in the intermediate *Cloud_Mask_Cloudiness* array, the following logic is used. If the Cloud Mask Status Flag is set to 1 (determined), then L2 pixels with Cloud Mask Cloudiness Flags set to either 0 (confident cloudy) or 1 (probably cloudy), are assigned a 1 or True. If the Cloud Mask Status Flag is set to 1 (determined), then L2 pixels with Cloud Mask Cloudiness Flags set to either 2 (probably clear) or 3 (confident clear), are assigned a 0 or False.

Finally, the L3 cloud fraction from cloud mask (Cloud_Fraction) is calculated in Yori and written to the L3 CLDPROP product by taking the mean value of the 1s and 0s in the intermediate *Cloud_Mask_Cloudiness* array.

For example, consider the 1x1 degree L3 grid box shown in Figure 16. Then the L3 Yori code does the following:

1. Toss out any Fill Value (-9999) encountered, and
2. with the remaining 1s and 0s (in each 1x1 degree L3 grid box) simply take the Mean of all the values -- that Mean will be the cloud fraction for that L3 grid box

In this example case of a single L3 1x1 degree grid box shown in Figure 16, there are 2 fill (missing) values (-9999) that are tossed out or ignored. This leaves 10 valid L2 pixels or observations in the L3 Grid Box (0s and 1s). There were 3 pixels or observations assigned cloudy or true (1.0) and 7 pixels or observations assigned clear or false (0.0). The Mean of those 0s and 1s is 0.300.

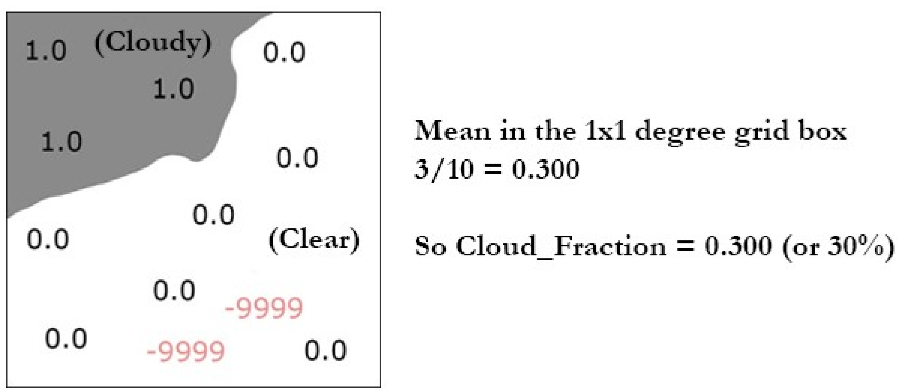


Figure 16. A theoretical example 1x1 degree L3 grid cell displaying a hypotherical sample of the intermediate Cloud_Mask_Cloudiness array of 1s (true or cloudy) and 0s (false or clear) that are used to compute cloud fractions in L3 by computing the mean of those numbers.

Cloud Fraction = Sum / Pixel_Counts = Mean = 3 / 10 = 0.300 (or 30% cloudy)

So the output Cloud Fraction, in this theoretical 1x1 degree L3 Grid Box, will be 0.300. To complete the job, Yori simply continues to build up the remaining grid cells in the 360 x 180 degree L3 Map in the same manner.

4.2.3.2. Cloud Fraction based on Successful Cloud Optical Property Retrievals (by cloud phase)

The second-most utilized L3 cloud fraction is that derived from the Cloud Optical Properties retrieval. All optical property cloud fractions are computed for **daytime scenes only** (Solar Zenith Angle (SZA) ≤ 80°).

The L3 CLDPROP product, the following aggregations of Cloud Optical Property Cloud Fractions are available in the following L3 Groups (or Parameters):

- Cloud_Retrieval_Fraction_Liquid
- Cloud_Retrieval_Fraction_Ice
- Cloud_Retrieval_Fraction_Undetermined
- Cloud_Retrieval_Fraction_Combined

The first parameter in the list above represents the cloud retrieval fraction for liquid water phase clouds only; the second, ice phase clouds only; the third, undetermined phase clouds only; and the fourth, combined phase clouds.

The optical property cloud fraction is computed in L3 using two QA Flags read from the L2 CLDPROP SDS called *Quality_Assurance*. These two QA Flags are: the *Primary Cloud Retrieval Phase Flag and the Primary Cloud Retrieval Outcome Flag*. See Table 6.

To compute Cloud Retrieval Fractions (from the Cloud Optical Property Algorithm) using Yori, intermediate L2 arrays are created in the Pre-Yori step called *COPR_** (where * is an acronym for the cloud phase).

These intermediate *COPR_** arrays are (as before for the *Cloud_Mask_Cloudiness arrays*) filled with 1s (True) and 0s (False). The 1s represent L2 pixels that are true (or cloudy that also meet some preset requirement specified, e.g., liquid water cloud phase) for the computation of the particular cloud fraction. The 0s represent L2 pixels that are either false (because they were deemed clear) or false (because they did not meet the requirements specified for that particular fraction (e.g. ice phase clouds). Therefore, if one is computing Liquid Water Cloud Fraction, 1s (T) can only be set if the L2 pixel is both cloudy and if the clouds were tagged Liquid Water Phase.

The logic used was as follows: every sampled L2 grid point that has a *Primary Cloud Retrieval Outcome Flag* = 1 (Retrieval Successful) and a *Primary Cloud Retrieval Phase Flag* of 2 (Liquid Water Cloud), 3 (Ice Cloud), or 4 (Undetermined Phase Cloud) are taken as 100% cloudy for the cloud phase category in question.

L2 QA Flag	Flag Value	Meaning
Primary Cloud Retrieval Phase Flag	0	Cloud Mask Undetermined (Missing or Fill)
	1	Not Processed (Typically Clear)
	2	Liquid Water Cloud
	3	Ice Cloud
	4	Undetermined Phase Cloud
Primary Cloud Retrieval Outcome Flag	0	Retrieval Not Attempted or Unsuccessful
	1	Retrieval Successful

Table 6. Two key L2 QA Flags used to compute the Cloud Optical Properties Cloud Fraction.

Key to remember, there was a change in how the Cloud Optical Property L3 Cloud Fractions were computed between MODIS Standard Collection 5/51 and Collection 6. In MODIS Standard Collection 6 (C6) and later, it was decided to include failed retrievals (in the counts used in the denominator of the L3 cloud fraction computation). This same MODIS Standard C6 logic (to include failed retrievals in this computation as false or 0) is used in L3 CLDPROP.

One note about the *Primary Cloud Retrieval Phase Flag* in Table 6. Flag values of 1 (Not Processed) are counted as clear sky. These retrievals will always have a *Retrieval Outcome Flag* of 0 (Unsuccessful).

So in summary, in the MODIS Standard L3 Product files for Collection 6 and later, and in the Continuity L3 CLDPROP files, the Cloud Optical Properties Cloud Fraction uses clear pixels, successfully retrieved pixels, **and unsuccessfully retrieved pixels**, in the computation of the (pseudo) mathematical denominator. Only successfully retrieved pixels that met the set cloud phase logic are used in the (pseudo) mathematical numerator.

Keeping in mind the logic described previously for the Cloud Fraction Computation in L3 CLDPROP, the Mean of those T/F pixels are tallied to compute the fraction. See Figure 17.

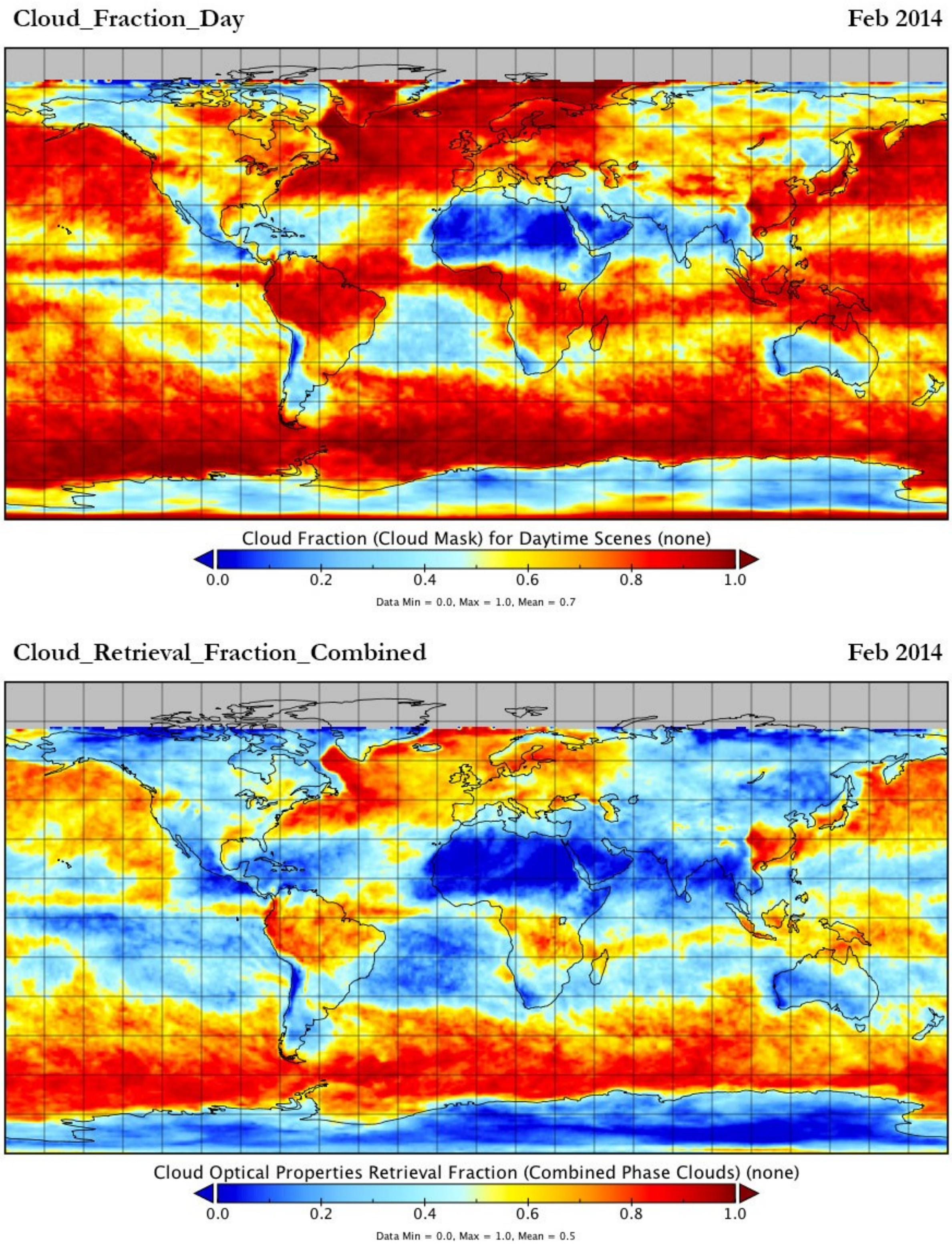


Figure 17. CLDPROP (VIIRS) Monthly Images for Feb 2014 (a) Cloud Fraction from Cloud Mask for Daytime only (b) Successful Cloud Optical Property Retrieval Fraction for Combined Phase Clouds (Daytime) The scale on both images span the full range of data: 0.0 (0%) to 1.0 (100%).

Finally, in order to provide a relatively easy way for L3 data users to keep track of the total number of pixels in these various key categories (successful & phase, unsuccessful & phase, cloud mask clear sky, and clear sky restoral) – histograms were added to both the L3 MODIS Standard Collection 6/61 and the L3 Continuity CLDPROP files. These four histograms are called:

- COP_Phase_Cloudy (dimension=3)
    - Counts in 3 categories are stored: Liquid Water, Ice, Undetermined Phase
    - Both Retrieval Success and Failure pixels are included
    - Clear Sky Restoral (CSR) Flag = 0, which means not restored (i.e., "cloudy")
- COP_Phase_Partly_Cloudy (dimension=3)
    - Counts in 3 categories are stored: Liquid Water, Ice, Undetermined Phase
    - Both Retrieval Success and Failure pixels are included
    - Cloud Sky Restoral (CSR) Flag = 1 or 3, which means "partly cloudy"
- COP_Phase_CloudMaskClear (dimension=1)
    - Counts in 1 category are stored: Cloud Mask Clear
    - Clear Sky Restoral (CSR) Flag = 0, which means not restored (i.e., "the pixel was already set to clear")
- COP_Phase_RestoredToClear (dimension=1)
    - Counts in 1 category are stored: Cloud Optical Properties said restore to clear, even though Cloud Mask said cloudy
    - Cloud Sky Restoral (CSR) Flag = 2, which means "restored to clear"

These four histograms provide a simple way for users to determine the counts of pixels in these 8 categories without having to post=process L3 data.

4.2.3.3. Logarithm Statistics.

Logarithms are another type of statistic not directly computable by Yori. Again, the Pre-Yori step was utilized to pre-process (or set-up) new L2 intermediate arrays, which could then be used by Yori to produce Log statistics.

This patch does precipitate a very minor array difference in MODIS Standard (MOD08) vs. Continuity (CLDPROP) Products. In the MODIS Standard Products, Log was a 'statistic type'; however with this patch required in Yori, Log is now an actual new Group (or Parameter) in the Continuity L3 CLDPROP product.

Please note that these Log statistics are only computed for cloud optical thickness (τ_c) parameters. The reason for this is as follows: because of the curvature of cloud reflectance as a function of optical thickness, the mean optical thickness of an ensemble of pixels does not correspond to the mean reflectance (or albedo) of those pixels. However, the mean of log(τ_c) approximates the radiatively-averaged optical thickness because reflectance plotted as a function of log(τ_c) is linear over a wide range of optical thickness (excluding small and large values). That is, the mean of log(τ_c) gives an optical thickness that approximately corresponds to the average reflectance of the pixels that comprise the mean. The accuracy of this approximation depends on the nature of the optical thickness probability density function (PDF). Studies on the validity of this approximate for MODIS scenes as reported by Oreopoulos et al. (2007). A similar study on ice clouds by the same authors is ongoing.

This Pre-Yori Log software patch turned out to be much easier to code than the more complex Cloud Fraction patch noted in the previous section. The Log set-up arrays were made by simply taking the Log (base 10) of Cloud Optical Thickness and creating a new intermediate input L2 array called *Cloud_Optical_Thickness_Log*. Next, that new array is simply run through the canned Yori routines to produce the suite of 5 simple Log statistics (Mean, Standard_Deviation, etc.).

Since for the Log computation, L2 cloud optical thicknesses (τ_c) are converted to base 10 logs, the following mapping can be laid out. A τ_c of 100 would be converted to a log value of 2.0, a τ_c of 10 would be converted to a log value of 1.0, a τ_c of 1.0 would be converted to a log value of 0, a τ_c of 0.1 would be converted to a log value of –1.0, and finally a τ_c of 0.01 (the smallest reported value in L2) would be converted to a log value of –2.0. So the valid range of this Log statistic would normally be -2.0 to 2.0 (corresponding to regular Cloud Optical Thickness data values ranging from 0.01 to 100). However, at the start of MODIS Standard C6, the maximum reported cloud optical thickness was increased from 100 to 150 in the cloud retrieval algorithm, which means the maximum log value is now 2.176 instead of 2.0. Once the log values of the L2 input pixel data are calculated in the Pre-Yori step, a daily mean value of all the log values is computed.

Figure 18 shows an illustrative comparison of traditional Cloud Optical Thickness imagery vs. Cloud Optical Thickness **Log** imagery. These images are for the exact same month of data, February 2014.

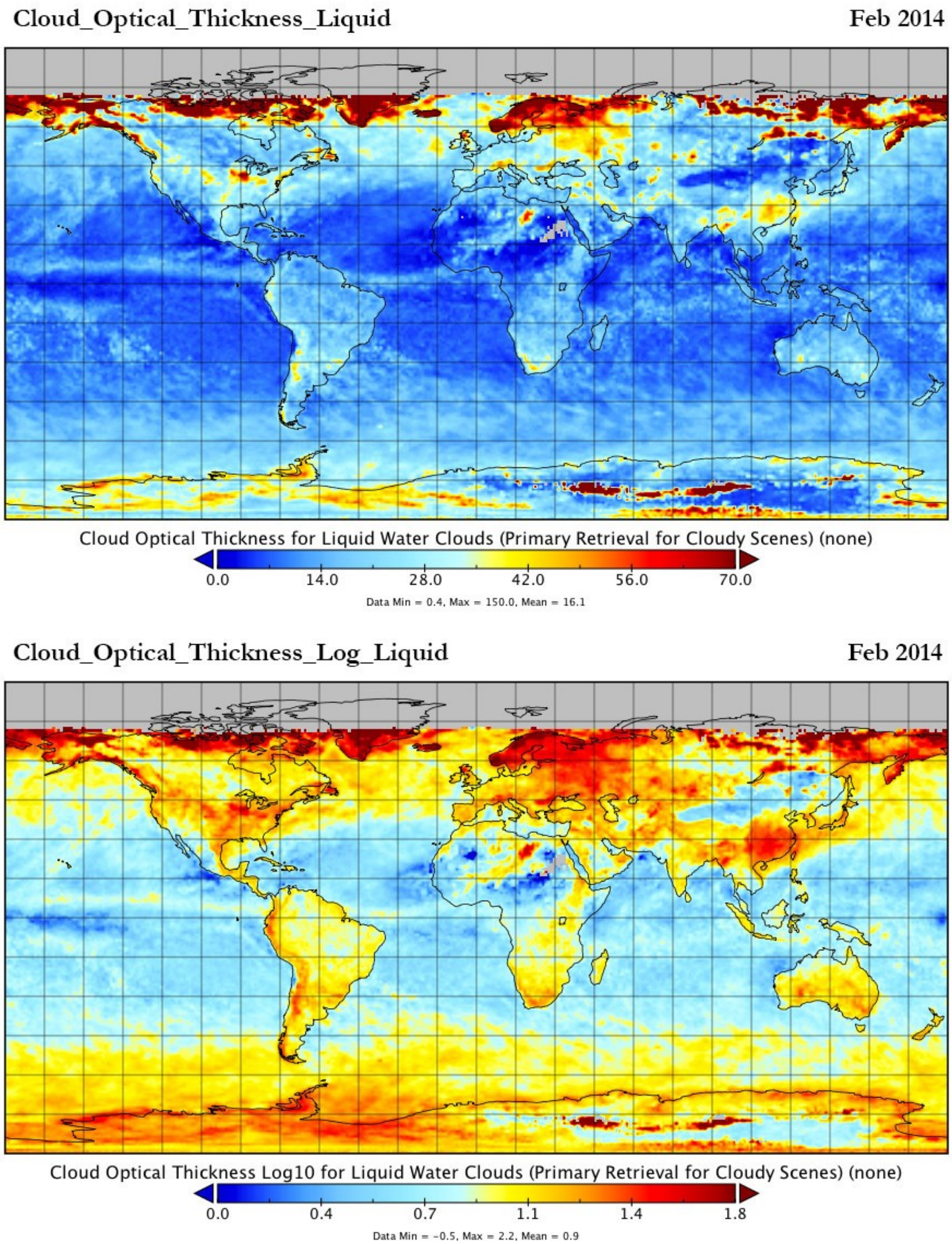


Figure 18. CLDPROP (VIIRS) Monthly Images for Feb 2014 (a) Cloud Optical Thickness for Liquid Water Phase Clouds (valid range from 0.01 to 150.0) (b) The Logarithm (Log) of that exact same data (valid range from -2.0 to 2.176). Note the image scale ranges were tweaked to provide more detail.

4.2.3.4. Uncertainty Statistics.

The final type of statistic not directly computable by Yori is uncertainty. However, for this statistic, it was not possible to "jury-rig" the Pre-Yori step to solve this shortcoming. Instead, a "punt" solution was adopted to give users the inputs needed to provide them the opportunity to compute uncertainty later on through post-processing.

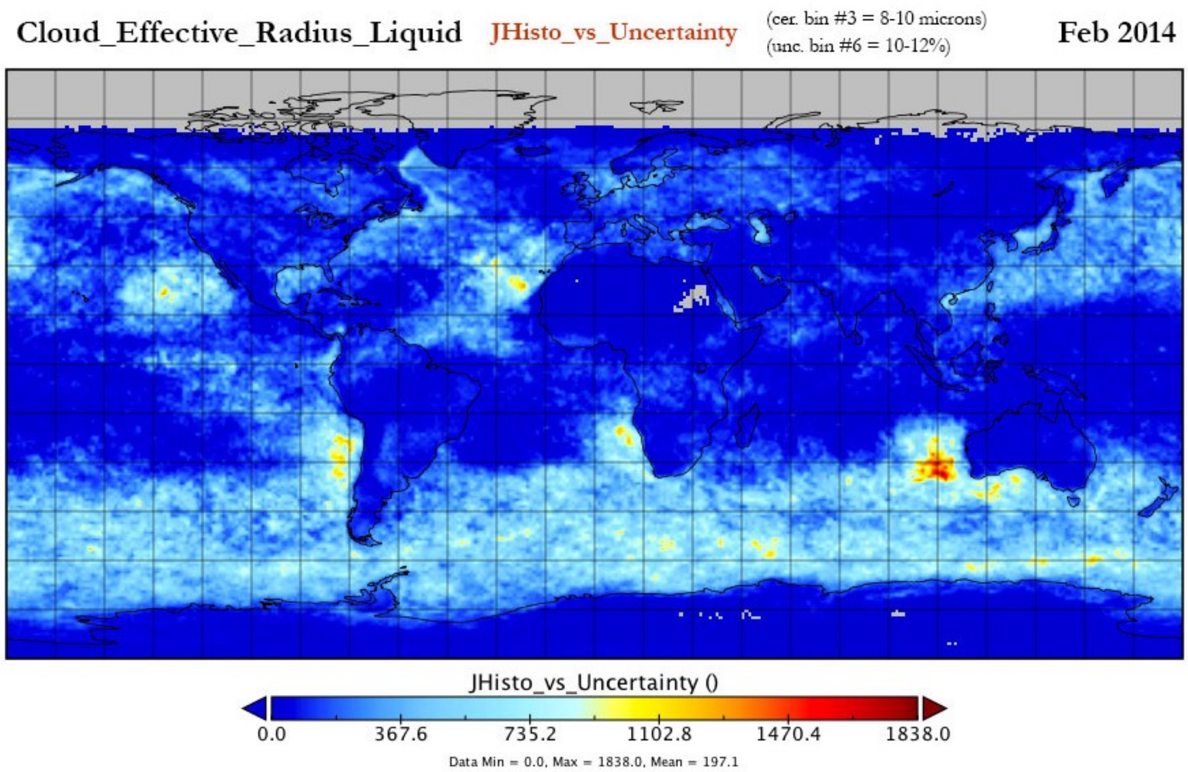
To provide the needed inputs for this future post-processing capability, L3 joint histograms of the sampled L2 parameter vs. the sampled L2 relative uncertainty (in %) were added.

The L2 CLDPROP development team provided the optimal L3 joint histogram bin boundaries for % uncertainly. These % uncertainty bin boundaries are uniformly defined in L3 CLDPROP as: [0, 2, 4, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 150, 200]; for a total of 21 uncertainty bins.

Also note that a total of 57 "JHisto_vs_Uncertainty" joint histogram statistics were defined, which covers a significant number of L3 CLDPROP Groups (or Parameters). See Table 8 in Section 7.0, for a complete rundown of Groups (or Parameters) that have these JHisto_vs_Uncertainty statistics defined.

Figure 19 shows two global maps of particular joint histogram bin combinations of the Joint Histogram vs. Uncertainty statistic. The top image shows a global map of the Cloud Effective Radius Liquid pixel counts for CER bin #3 (8-10 microns) and Uncertainty bin #6 (10-12%). The bottom image shows a global map of the Cloud Effective Radius Liquid pixel counts for the same CER bin #3 (8-10 microns), but this time for Uncertainty bin #12 (35-40%).

Power users of L3 CLDPROP data who are interested in using these Joint Histograms of Uncertainty to post-process L3 grid-level uncertainties should refer to Appendix C of this document for more details.



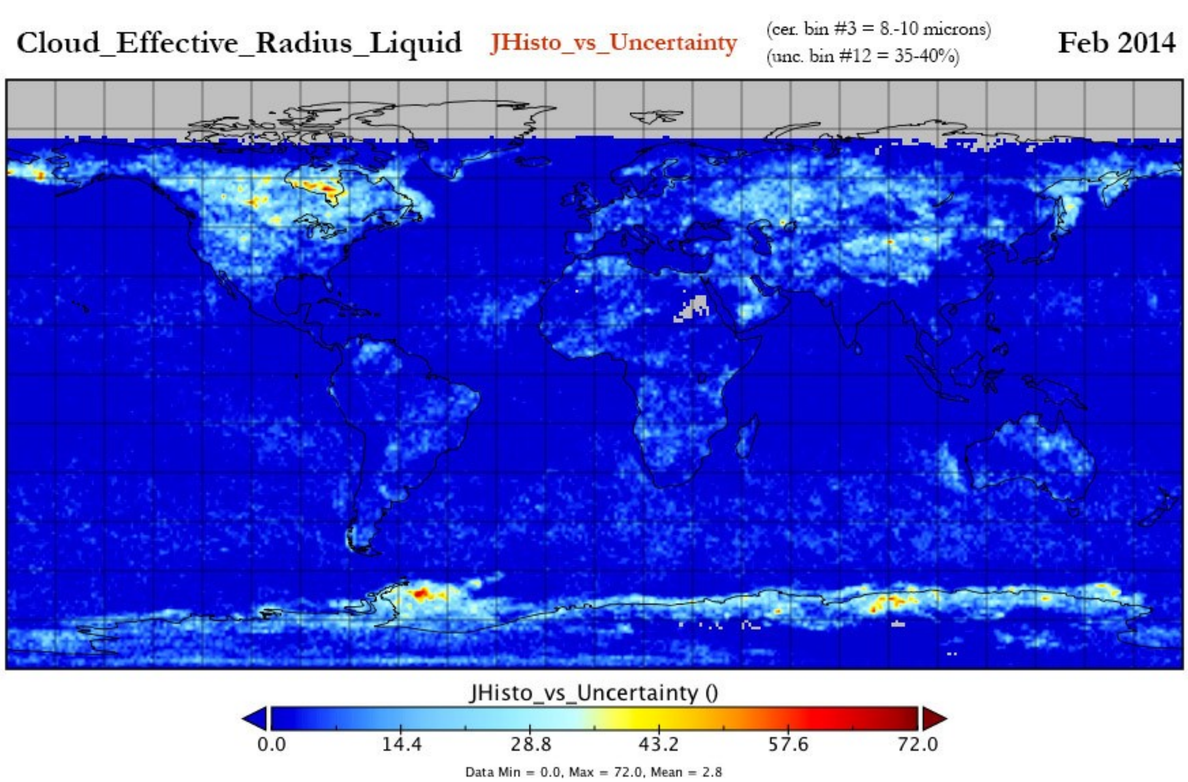


Figure 19. CLDPROP (VIIRS) Monthly Images for Feb 2014. Liquid Water Cloud Effective Radius (a) Joint Histogram vs. Uncertainty Counts for Re 8-10 & Uncertainty 10-12% (b) Joint Histogram vs. Uncertainty Counts for Re 8-10 & Uncertainty 35-40%.

5.0. Computation of L3 Monthly Statistics

Since the exact same YAML (Markup Language) Configuration File and Yori Processing System is used to produce both Daily (D3) and Monthly (M3) files, there is little chance of anything going askew in the Monthly product only. If the Daily is being computed correctly and producing valid results, then the Monthly will follow. That being said, both the Daily and Monthly products rely on correct and valid upstream L2 input products.

Because of this processing algorithm matching paradigm, L3 CLDPROP Daily and Monthly products have identical mapping grids and resolution, identical parameter and statistic inventory lists, and identical histograms and joint histograms (including bin boundary definitions).

It's interesting to note that only the L3 Daily files are used as direct input into the Monthly product, however because L2-tied quantities Sum and Sum_Squares are carried through the Daily and Monthly file, statistics in the Monthly file continue to reflect the L2 input data directly. This means quantities of standard deviation in the Monthly (M3) file are actually the standard deviation of the L2 input pixels, which is the most useful and meaningful way to compute standard deviation.

As a bit of background on the standard deviation computation, in the MODIS Standard Monthly file (MOD08_M3), there were two different standard deviations computed: 1.) the standard deviation of the daily means, and 2.) the mean of the daily standard deviation; however nowhere in the MODIS Standard Monthly product (08_M3) was a statistic describing the standard deviation of the L2 input pixels, since the pieces required to compute that information in the monthly file were not available in the Daily (08_D3) file. Therefore, the L3 CLDPROP Monthly product file is superior to the L3 MODIS Standard Monthly product file in that regard.

Also true in the MODIS Standard L3 (08_D3, 08_M3) as well as the Continuity CLDPROP L3 (CLDPROP_D3, CLDPROP_M3), there is no "valid_range" check -- only fill value L2 grid cells are universally excluded. Valid_range is reported in the YAML configuration file and in the NetCDF4 file as local attributes attached to each Group, however it's for documentation purposes only.

Finally, users should also note that in L3 CLDPROP Monthly file (CLDPROP_M3), all mean and standard deviation quantities are pixel-count weighted. While in the MODIS Standard Monthly file (08_M3), some monthly means were pixel-count weighted (cloud optical property related statistics) and some monthly means were unweighted (cloud top property and cloud mask related statistics). See Tables 7a and 7b, below.

MODIS Standard MOD08_M3 or MYD08_M3 (Collection 6.1)

Major Parameter Groups	Unweighted Scheme	Pixel-Count Weighted Scheme
Cloud Top Properties / Cloud Mask	√	
Cloud Optical Properties		√

Table 7a. This Table shows the Weighting Scheme used in the MODIS Standard L3 Monthly Products (unwieghted scheme for CTP and CM -related parameters; and pixel-count weighted scheme for COP-related parameters). The weighting scheme used was selected in advance by each science team for their products.

Continuity CLDPROP_M3 (Version 1.1)

Major Parameter Groups	Unweighted Scheme	Pixel-Count Weighted Scheme
Cloud Top Properties / Cloud Mask	n/a	√
Cloud Optical Properties	n/a	√

Table 7b. This Table shows the Weighting Scheme used in the Continuity L3 Monthly Products. Users should be aware of the change in the weighting scheme used to compute CTP and CM related Monthly (M3) statistics between the Heritage MODIS Standard 08_M3 (Table 7a) and Continuity CLDPROP_M3 (Table 7b). Note that the Unweighted Scheme is not available in the YORI SIPS L3 processing system, so it is not an option.

Figure 20 shows how these two different monthly (M3) weighting schemes (unweighted vs. pixel-count weighted) can affect statistics. The solid lines show MODIS Aqua (blue) and VIIRS SNPP (red) Daytime Cloud Fractions (60N to 60S) using an unweighted scheme (08_M3), so that each daily mean has the same 1x weight in the computation of the monthly mean.

The dashed lines show MODIS Aqua (blue dash) and VIIRS SNPP (red dash) for the same data using a pixel-count weighted scheme (CLDPROP_M3), so that each daily mean is weighted by the number of valid L2 pixels that make up that daily mean. It's interesting to note that the MODIS Aqua data (blue lines) shows more of an impact in this change of weighting scheme than VIIRS SNPP data (red lines), roughly 1.5% vs. 0.5%, respectively. In any case, it's clear that the weighting scheme used to compute monthly means does make a difference in the values.

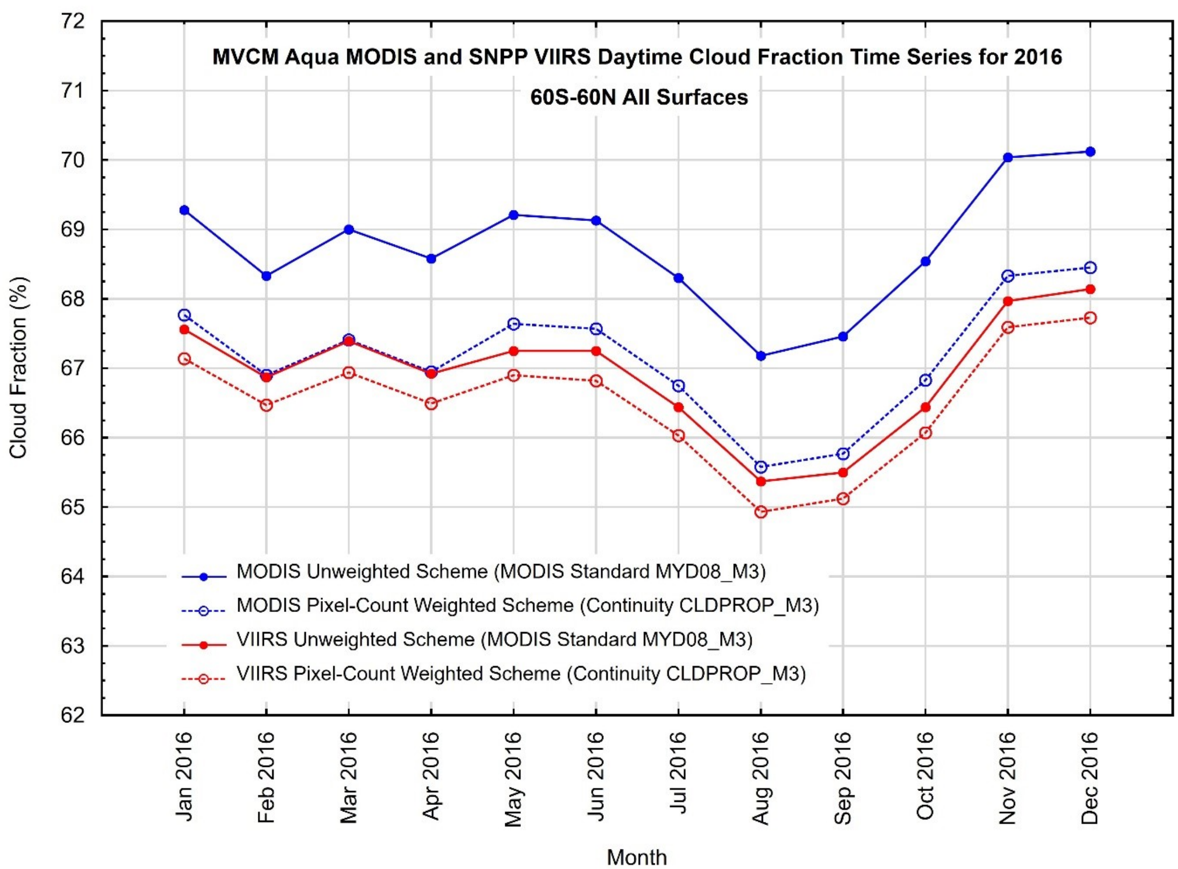


Figure 20. Users should be aware of the change in the weighting scheme used to compute some Monthly (M3) statistics between the Heritage MODIS Standard 08_M3 (Unweighted Scheme) and Continuity CLDPROP_M3 (Pixel-Count Weighted Scheme). Figure courtesy Rich Frey UW SSEC.

6.0. Reading and Unpacking NetCDF4 File Data

NetCDF4 (Network Common Data Form, v4) is a set of software libraries and self-describing, machine-independent, multi-object data formats that support the creation, access, and sharing of array-oriented scientific data. NetCDF was developed by and is maintained at Unidata, which is part of the University Corporation for Atmospheric Research (UCAR) Community Programs (UCP). NetCDF4 is the standard data format for Atmosphere Continuity CLDPROP data products.

6.1. Descaling data

The standard NetCDF4 file local attributes "scale_factor" and "add_offset," attached to every Group, would typically only apply to the Mean and Standard_Deviation statistics (which are the only two statistics in L3 CLDPROP that could be realistically packed) and in that case, would be used for the conversion of stored (packed) integer data to geophysical floating point numbers through the use of the following equation:

$$\text{Geophysical Value} = \text{scale\_factor} * (\text{Stored Integer} - \text{add\_offset}) \qquad (8)$$

However in L3 CLDPROP files, the Mean and Standard_Deviation statistics are stored as double-precision real (R*8) numbers that are not natively packed, therefore no end-user unpacking needs to occur. So for all Groups (Parameters) in L3 CLDPROP, the scale_factor local attribute is set to 1.0 and the add_offset local attribute is set to 0.0.

All L3 count-related statistics (Pixel_Counts, Histogram_Counts, and JHisto_vs_xxx) are stored as 4 byte Integer (I*4) or INT. INT numbers can range up to 2,147,483,647, which is enough headroom to store any possible real-world count from sampled MODIS or VIIRS instrument data at larger L3 grid sizes, even at longer time intervals. The Pixel_Counts will always contain the largest numbers of these three count-related statistics, since those counts are not subdivided into data-value bins.

The Sum and Sum_Squares statistics are stored as double-precision Real (R*8), the same format as the Mean and Standard_Deviation. The Sum_Squares numbers can get astronomically large. The Sum and Sum_Squares data is really only provided (available) in order to compute other statistics (e.g.: Mean and Standard_Deviation) as Yori aggregate data, and rarely need to be read by the science or user community.

The scientific measuring units of the geophysical floating point Mean and Standard Deviation values are indicated by the "units" local attribute that is also provided with each Group.

Valid range local attributes (given as a min (value_min) and max (value_max) number) is also provided with each Group. The two valid range values provided are the expected low and high values of valid (non-fill) L2 input to the L3 statistic data.

Note that **no** valid range screening on the input L2 data or the output L3 data is performed. The reason for this is sometimes absolute valid ranges are difficult to determine in advance and the algorithm developers want to avoid the potential loss of good data. Therefore, users should not be surprised to find non-fill data points that fall outside the documented valid-range; however it should raise a flag for the user to make sure they are unpacking the data correctly.

6.2. Definitions of local attributes

As partially described above, attached to each Group within a NetCDF4 file are a suite of local attributes (some described in the previous section). These local attributes serve as a key to interpret the data, drive the logic in the Yori system, and provide documentation for end users.

6.2.1. Local attributes used in L3 CLDPROP files.

Given below is the full set of local attributes, which can be attached to specific Groups (Parameters) or Variables (Statistics) in the L3 CLDPROP files. Note that not all of these are attached to every Group and Variable (only the local attributes necessary to compute or properly document the statistics in the Group).

- **long_name.** A longer character string description of the Group.
- **units.** Scientific measuring units of the data (if there are no units, "none" is specified).

- **valid_min, valid_max.** An array of two numbers that describe the expected low and high values (valid range) of the L2 data (before applying any scale and offset in L2, if L2 data was packed); ignoring the L2 Fill Value.
- **scale_factor.** If the data is packed, this is the scaling factor used to unpack the data. Note for L3 CLDPROP files, this is always set to 1.0 (which means no packing was done).
- **add_offset.** If the data is packed, this is the offset used to unpack the data. Note for L3 CLDPROP files, this is always set to 0.0 (which means no packing was done).
- **_FillValue.** The value of missing or fill data in the Group (Parameter) or Variable (Statistics). Typically set to -9999 in the L3 CLDPROP file.
- **title.** A character array providing a succinct description of what is in the variable. Note that this attribute is attached to all variables in the L3 CLDPROP NetCDF4 file and provides information to various visualization packages (e.g., Panoply) on how to explicitly title images produced from that variable (typically this is a combination of the Group name and the Variable name).
- **Histogram_Bin_Boundaries.** An array of numbers describing the histogram bin boundaries of the primary parameter. (Only used when an optional histogram (Histogram_Count) statistic is defined.)
- **JHisto_Bin_Boundaries.** An array of numbers describing the joint histogram bin boundaries of the primary parameter. (Only used when an optional joint histogram (JHisto_vs_xxx) statistic is defined.)
- **JHisto_Bin_Boundaries_Joint_Parameter.** An array of numbers describing the histogram bin boundaries of any secondary (or jointed) parameter. (Only used when an optional joint histogram (JHisto_vs_xxx) statistic is defined.)

7.0. Complete Group & Variable Inventory of L3 CLDPROP

Table 8 below shows a complete inventory of Groups and Variables in the L3 CLDPROP products. The Groups (or Parameters) are shown in the rows of the table. The Variables (or Statistics) are shown in the columns of the table. Statistics that are computed for each Group are reprented by colored dots in the table. A dot means that statistic exists (shown in the column) for that particular parameter (shown in the row).

The color coding of the statistic colums was done to help differentiate groups of statistics. This table was compiled based on L3 CLDPROP Data Version 1.0 (File Version 001), and should remain relatively stable for future versions.

The number of Groups (Parameters) total 128, the number of possible Variables (Statistics) that can be defined for each Group number 14. The total number of Group/Variable (or Parameter/Statistic) combinations total 837. Of these 837 Parameter/Statistic combinations, 630 are scalar statistics, 78 are 1D histograms, and 129 are 2D Joint Histograms.

	Mean	Standard_Deviation	Sum	Sum_Squares	Pixel_Counts	Histogram_Counts (n)	JHisto_vs_Pressure (nxm)	JHisto_vs_Temperature (nxm)	JHisto_vs_Emissivity (nxm)	JHisto_vs_Eff_Radius (nxm)	JHisto_vs_Eff_Radius_16 (nxm)	JHisto_vs_Eff_Radius_37 (nxm)	JHisto_vs_Eff_Radius_1621 (nxm)	JHisto_vs_Uncertainty (nxm)
Solar and Sensor Angles (4)														
01. Solar_Zenith (Masked w. Cloud Mask Day Flag (≤ 85°) to match MODIS L3)	•	•	•	•	•									
02. Solar_Azimuth (Masked w. Cloud Mask Day Flag)	•	•	•	•	•									
03. Sensor_Zenith (Masked w. Cloud Mask Day Flag) Masked All: VZA LE 65.5°	•	•	•	•	•									
04. Sensor_Azimuth (Masked w. Cloud Mask Day Flag)	•	•	•	•	•									

Cloud Top Properties (CTP) *(21)* *JH=21*

[CTP 06_L2 Algo Day: SZA ≤ 85°] [New CTP CLDPROP Algo Day: SZA ≤ 80°]

	Mean	Standard_Deviation	Sum	Sum_Squares	Pixel_Counts	Histogram_Counts (n)	JHisto_vs_Pressure (nxm)	JHisto_vs_Temperature (nxm)	JHisto_vs_Emissivity (nxm)	JHisto_vs_Eff_Radius (nxm)	JHisto_vs_Eff_Radius_16 (nxm)	JHisto_vs_Eff_Radius_37 (nxm)	JHisto_vs_Eff_Radius_1621 (nxm)	JHisto_vs_Uncertainty (nxm)
01. Cloud_Top_Pressure	•	•	•	•	•	•			•					•
02. Cloud_Top_Pressure_Day	•	•	•	•	•	•			•					•
03. Cloud_Top_Pressure_Night	•	•	•	•	•	•			•					•
04. Cloud_Top_Temperature	•	•	•	•	•	•	•							•
05. Cloud_Top_Temperature_Day	•	•	•	•	•	•	•							•
06. Cloud_Top_Temperature_Night	•	•	•	•	•	•	•							•
07. Cloud_Top_Height	•	•	•	•	•	•	•							•
08. Cloud_Top_Height_Day	•	•	•	•	•	•	•							•
09. Cloud_Top_Height_Night	•	•	•	•	•	•	•							•
10. Cloud_Effective_Emissivity	•	•	•	•	•	•	•							
11. Cloud_Effective_Emissivity_Day	•	•	•	•	•	•	•							
12. Cloud_Effective_Emissivity_Night	•	•	•	•	•	•	•							
13. Cloud_Fraction [Computed from Cloud_Mask_Cloudiness]	•	•	•	•	•									
14. Cloud_Fraction_Day [Cloud Mask Algo Day: SZA ≤ 85°]	•	•	•	•	•									
15. Cloud_Fraction_Night	•	•	•	•	•									
16. Cloud_Mask [4 cats: Conf.Cldy, Prob.Cldy, Prob.Clr, Conf.Clr] Det.=1						•								
17. Cloud_Mask_Day [4 cats: Conf.Cldy, Prob.Cldy, Prob.Clr, Conf.Clr] Det.=1						•								
18. Cloud_Mask_Night [4 cats: Conf.Cldy, Prob.Cldy, Prob.Clr, Conf.Clr] Det.=1						•								
19. CTP_Phase [5 cats: Clear, Liq.Water, Ice, Mixed, Undet.]						•								
20. CTP_Phase_Day [5 cats: Clear, Liq.Water, Ice, Mixed, Und.]						•								
21. CTP_Phase_Night [5 cats: Clear, Liq.Water, Ice, Mixed, Und.]						•								

	Mean	Standard_Deviation	Sum	Sum_Squares	Pixel_Counts	Histogram_Counts (n)	JHisto_vs_Pressure (nxm)	JHisto_vs_Temperature (nxm)	JHisto_vs_Emissivity (nxm)	JHisto_vs_Eff_Radius (nxm)	JHisto_vs_Eff_Radius_16 (nxm)	JHisto_vs_Eff_Radius_37 (nxm)	JHisto_vs_Eff_Radius_1621 (nxm)	JHisto_vs_Uncertainty (nxm)

Cloud Optical Properties (COP) *(103)* *JH=105*

(Primary 2.1 µm Retrieval) *(43)* *JH=37*

[COP 06_L2 Algo: SZA ≤ 81.3731°] [New COP CLDPROP Algo: SZA ≤ 80°]

01. Cloud_Optical_Thickness_Liquid	•	•	•	•	•	•	•	•		•				•
02. Cloud_Optical_Thickness_Ice	•	•	•	•	•	•	•	•	•	•				•
03. Cloud_Optical_Thickness_Undetermined	•	•	•	•	•	•								
04. Cloud_Optical_Thickness_Combined	•	•	•	•	•	•								
05. Cloud_Optical_Thickness_ISCCP							•							
06. Cloud_Optical_Thickness_Log_Liquid	•	•	•	•	•									
07. Cloud_Optical_Thickness_Log_Ice	•	•	•	•	•									
08. Cloud_Optical_Thickness_Log_Undetermined	•	•	•	•	•									
09. Cloud_Optical_Thickness_Log_Combined	•	•	•	•	•									
10. Cloud_Optical_Thickness_PCL_Liquid	•	•	•	•	•	•	•	•		•				•
11. Cloud_Optical_Thickness_PCL_Ice	•	•	•	•	•	•	•	•	•	•				•
12. Cloud_Optical_Thickness_PCL_Undetermined	•	•	•	•	•	•								
13. Cloud_Optical_Thickness_PCL_Combined	•	•	•	•	•	•								
14. Cloud_Optical_Thickness_PCL_ISCCP							•							
15. Cloud_Optical_Thickness_PCL_Log_Liquid	•	•	•	•	•									
16. Cloud_Optical_Thickness_PCL_Log_Ice	•	•	•	•	•									
17. Cloud_Optical_Thickness_PCL_Log_Undetermined	•	•	•	•	•									
18. Cloud_Optical_Thickness_PCL_Log_Combined	•	•	•	•	•									
19. Cloud_Effective_Radius_Liquid	•	•	•	•	•	•	•	•						•
20. Cloud_Effective_Radius_Ice	•	•	•	•	•	•	•	•						•
21. Cloud_Effective_Radius_Undetermined	•	•	•	•	•	•								
22. Cloud_Effective_Radius_PCL_Liquid	•	•	•	•	•	•	•	•						•
23. Cloud_Effective_Radius_PCL_Ice	•	•	•	•	•	•	•	•						•

	Mean	Standard_Deviation	Sum	Sum_Squares	Pixel_Counts	Histogram_Counts (n)	JHisto_vs_Pressure (nxm)	JHisto_vs_Temperature (nxm)	JHisto_vs_Emissivity (nxm)	JHisto_vs_Eff_Radius (nxm)	JHisto_vs_Eff_Radius_16 (nxm)	JHisto_vs_Eff_Radius_37 (nxm)	JHisto_vs_Eff_Radius_1621 (nxm)	JHisto_vs_Uncertainty (nxm)
24. Cloud_Effective_Radius_PCL_Undetermined	•	•	•	•	•	•								
25. Cloud_Water_Path_Liquid [Range: 0 to 3000]	•	•	•	•	•	•								•
26. Cloud_Water_Path_Ice [Range: 0 to 6000]	•	•	•	•	•	•								•
27. Cloud_Water_Path_Undetermined	•	•	•	•	•	•								
28. Cloud_Water_Path_PCL_Liquid	•	•	•	•	•	•								•
29. Cloud_Water_Path_PCL_Ice	•	•	•	•	•	•								•
30. Cloud_Water_Path_PCL_Undetermined	•	•	•	•	•	•								
31. Cloud_Retrieval_Fraction_Liquid (COPR_LIQ derived)	•	•	•	•	•									
32. Cloud_Retrieval_Fraction_Ice	•	•	•	•	•									
33. Cloud_Retrieval_Fraction_Undetermined	•	•	•	•	•									
34. Cloud_Retrieval_Fraction_Combined	•	•	•	•	•									
35. Cloud_Retrieval_Fraction_PCL_Liquid (COPR_PCL_LIQ)	•	•	•	•	•									
36. Cloud_Retrieval_Fraction_PCL_Ice	•	•	•	•	•									
37. Cloud_Retrieval_Fraction_PCL_Undetermined	•	•	•	•	•									
38. Cloud_Retrieval_Fraction_PCL_Combined	•	•	•	•	•									
39. Cloud_Phase_Optical_Properties [L, I, U][Cld+PCL][S+F]								•						
40. COP_Phase_Cloudy [3 cats: Liq, Ice, Undet] CSR=0 [Succ+Fail]						•								
41. COP_Phase_Partly_Cloudy [3 cats: Liq, Ice, Undet] CSR=1,3 [S+F]						•								
42. COP_Phase_CloudMaskClear [1 cat: CloudMaskClear] CSR=0						•								
43. COP_Phase_RestoredToClear [1 cat: RestoredToClear] CSR=2						•								

(Supplementary 1.6 μm Retrieval) (20) *JH=28*

01. Cloud_Optical_Thickness_16_Liquid	•	•	•	•	•	•					•			•
02. Cloud_Optical_Thickness_16_Ice	•	•	•	•	•	•					•			•
03. Cloud_Optical_Thickness_16_Log_Liquid	•	•	•	•	•									
04. Cloud_Optical_Thickness_16_Log_Ice	•	•	•	•	•									
05. Cloud_Optical_Thickness_16_PCL_Liquid	•	•	•	•	•	•					•			•

	Mean	Standard_Deviation	Sum	Sum_Squares	Pixel_Counts	Histogram_Counts (n)	JHisto_vs_Pressure (nxm)	JHisto_vs_Temperature (nxm)	JHisto_vs_Emissivity (nxm)	JHisto_vs_Eff_Radius (nxm)	JHisto_vs_Eff_Radius_16 (nxm)	JHisto_vs_Eff_Radius_37 (nxm)	JHisto_vs_Eff_Radius_1621 (nxm)	JHisto_vs_Uncertainty (nxm)
06. Cloud_Optical_Thickness_16_PCL_Ice	●	●	●	●	●	●					●			●
07. Cloud_Optical_Thickness_16_PCL_Log_Liquid	●	●	●	●	●									
08. Cloud_Optical_Thickness_16_PCL_Log_Ice	●	●	●	●	●									
09. Cloud_Effective_Radius_16_Liquid	●	●	●	●	●	●		●		●		●		●
10. Cloud_Effective_Radius_16_Ice	●	●	●	●	●	●		●		●		●		●
11. Cloud_Effective_Radius_16_PCL_Liquid	●	●	●	●	●	●		●		●		●		●
12. Cloud_Effective_Radius_16_PCL_Ice	●	●	●	●	●	●		●		●		●		●
13. Cloud_Water_Path_16_Liquid	●	●	●	●	●	●								●
14. Cloud_Water_Path_16_Ice	●	●	●	●	●	●								●
15. Cloud_Water_Path_16_PCL_Liquid	●	●	●	●	●	●								●
16. Cloud_Water_Path_16_PCL_Ice	●	●	●	●	●	●								●
17. Cloud_Retrieval_Fraction_16_Liquid	●	●	●	●	●									
18. Cloud_Retrieval_Fraction_16_Ice	●	●	●	●	●									
19. Cloud_Retrieval_Fraction_16_PCL_Liquid	●	●	●	●	●									
20. Cloud_Retrieval_Fraction_16_PCL_Ice	●	●	●	●	●									

(Supplementary 3.7 μm Retrieval) (20) *JH=24*

	Mean	Standard_Deviation	Sum	Sum_Squares	Pixel_Counts	Histogram_Counts (n)	JHisto_vs_Pressure (nxm)	JHisto_vs_Temperature (nxm)	JHisto_vs_Emissivity (nxm)	JHisto_vs_Eff_Radius (nxm)	JHisto_vs_Eff_Radius_16 (nxm)	JHisto_vs_Eff_Radius_37 (nxm)	JHisto_vs_Eff_Radius_1621 (nxm)	JHisto_vs_Uncertainty (nxm)
01. Cloud_Optical_Thickness_37_Liquid	●	●	●	●	●	●						●		●
02. Cloud_Optical_Thickness_37_Ice	●	●	●	●	●	●						●		●
03. Cloud_Optical_Thickness_37_Log_Liquid	●	●	●	●	●									
04. Cloud_Optical_Thickness_37_Log_Ice	●	●	●	●	●									
05. Cloud_Optical_Thickness_37_PCL_Liquid	●	●	●	●	●	●						●		●
06. Cloud_Optical_Thickness_37_PCL_Ice	●	●	●	●	●	●						●		●
07. Cloud_Optical_Thickness_37_PCL_Log_Liquid	●	●	●	●	●									
08. Cloud_Optical_Thickness_37_PCL_Log_Ice	●	●	●	●	●									
09. Cloud_Effective_Radius_37_Liquid	●	●	●	●	●	●		●		●				●
10. Cloud_Effective_Radius_37_Ice	●	●	●	●	●	●		●		●				●

	Mean	Standard_Deviation	Sum	Sum_Squares	Pixel_Counts	Histogram_Counts (n)	JHisto_vs_Pressure (nxm)	JHisto_vs_Temperature (nxm)	JHisto_vs_Emissivity (nxm)	JHisto_vs_Eff_Radius (nxm)	JHisto_vs_Eff_Radius_16 (nxm)	JHisto_vs_Eff_Radius_37 (nxm)	JHisto_vs_Eff_Radius_1621 (nxm)	JHisto_vs_Uncertainty (nxm)
11. Cloud_Effective_Radius_37_PCL_Liquid	●	●	●	●	●	●		●		●				●
12. Cloud_Effective_Radius_37_PCL_Ice	●	●	●	●	●	●		●		●				●
13. Cloud_Water_Path_37_Liquid	●	●	●	●	●	●								●
14. Cloud_Water_Path_37_Ice	●	●	●	●	●	●								●
15. Cloud_Water_Path_37_PCL_Liquid	●	●	●	●	●	●								●
16. Cloud_Water_Path_37_PCL_Ice	●	●	●	●	●	●								●
17. Cloud_Retrieval_Fraction_37_Liquid	●	●	●	●	●									
18. Cloud_Retrieval_Fraction_37_Ice	●	●	●	●	●									
19. Cloud_Retrieval_Fraction_37_PCL_Liquid	●	●	●	●	●									
20. Cloud_Retrieval_Fraction_37_PCL_Ice	●	●	●	●	●									

(Supplem. 1.6-2.1 µm Retrieval) (20) JH=16

	Mean	Standard_Deviation	Sum	Sum_Squares	Pixel_Counts	Histogram_Counts (n)	JHisto_vs_Pressure (nxm)	JHisto_vs_Temperature (nxm)	JHisto_vs_Emissivity (nxm)	JHisto_vs_Eff_Radius (nxm)	JHisto_vs_Eff_Radius_16 (nxm)	JHisto_vs_Eff_Radius_37 (nxm)	JHisto_vs_Eff_Radius_1621 (nxm)	JHisto_vs_Uncertainty (nxm)
01. Cloud_Optical_Thickness_1621_Liquid	●	●	●	●	●	●							●	●
02. Cloud_Optical_Thickness_1621_Ice	●	●	●	●	●	●							●	●
03. Cloud_Optical_Thickness_1621_Log_Liquid	●	●	●	●	●									
04. Cloud_Optical_Thickness_1621_Log_Ice	●	●	●	●	●									
05. Cloud_Optical_Thickness_1621_PCL_Liquid	●	●	●	●	●	●							●	●
06. Cloud_Optical_Thickness_1621_PCL_Ice	●	●	●	●	●	●							●	●
07. Cloud_Optical_Thickness_1621_PCL_Log_Liquid	●	●	●	●	●									
08. Cloud_Optical_Thickness_1621_PCL_Log_Ice	●	●	●	●	●									
09. Cloud_Effective_Radius_1621_Liquid	●	●	●	●	●	●								●
10. Cloud_Effective_Radius_1621_Ice	●	●	●	●	●	●								●
11. Cloud_Effective_Radius_1621_PCL_Liquid	●	●	●	●	●	●								●
12. Cloud_Effective_Radius_1621_PCL_Ice	●	●	●	●	●	●								●
13. Cloud_Water_Path_1621_Liquid	●	●	●	●	●	●								●
14. Cloud_Water_Path_1621_Ice	●	●	●	●	●	●								●
15. Cloud_Water_Path_1621_PCL_Liquid	●	●	●	●	●	●								●

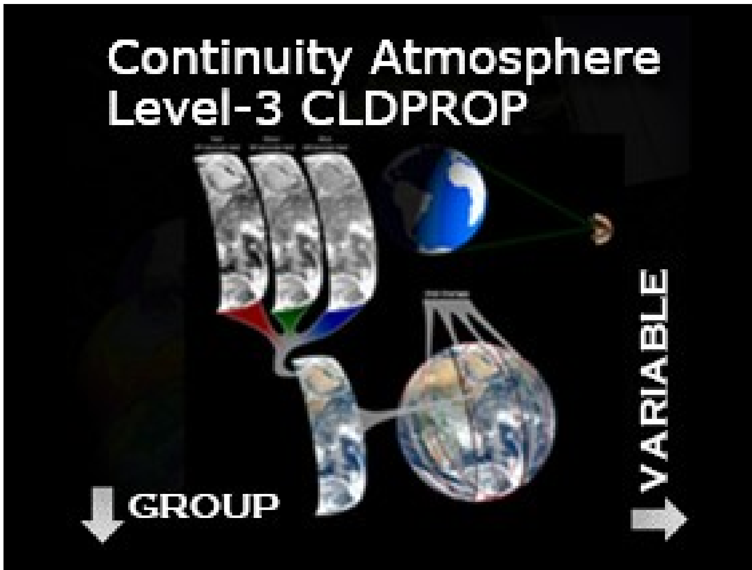
	Mean	Standard_Deviation	Sum	Sum_Squares	Pixel_Counts	Histogram_Counts (n)	JHisto_vs_Pressure (nxm)	JHisto_vs_Temperature (nxm)	JHisto_vs_Emissivity (nxm)	JHisto_vs_Eff_Radius (nxm)	JHisto_vs_Eff_Radius_16 (nxm)	JHisto_vs_Eff_Radius_37 (nxm)	JHisto_vs_Eff_Radius_1621 (nxm)	JHisto_vs_Uncertainty (nxm)
16. Cloud_Water_Path_1621_PCL_Ice	•	•	•	•	•	•								•
17. Cloud_Retrieval_Fraction_1621_Liquid	•	•	•	•	•									
18. Cloud_Retrieval_Fraction_1621_Ice	•	•	•	•	•									
19. Cloud_Retrieval_Fraction_1621_PCL_Liquid	•	•	•	•	•									
20. Cloud_Retrieval_Fraction_1621_PCL_Ice	•	•	•	•	•									

Table 8. A Complete Inventory of Groups (Parameters) and Variables (Statistics) in the L3 CLDPROP product. There are a total of 128 individual Groups (or Parameters) in the product, shown in the rows of the table. A dot in the table means that the particular Variable (Statistic) exists for that particular Group (Parameter). So the 837 dots in the table above, represent the 837 group/statistic combinations defined in the L3 CLDPROP product.

The NetCDF4 file size is roughly 500MB for Daily (D3) and 800 MB for Monthly (M3). The file format and structure is exactly the same between the Daily (D3) and Monthly (M3) NetCDF4 files.

8.0. Important Notes, Caveats, and Issues to Consider in CLDPROP L3

8.1. Cloud Mask Cloud Fraction: MOD08 vs. CLDPROP

In MODIS Standard L3 (MOD08), Cloud Fractions from Cloud Mask were produced at L2 (MOD06) on a 5x5km grid. These 5km average Cloud Fractions were then read into L3 (MOD08). Therefore, the L3 (MOD08) Cloud Fractions were derived from 5x5 km L2 averages.

In Continuity L3 (CLDPROP), the L2 input file did not contain any Cloud Fraction computed in advance (since L2 CLDPROP was a 1 km (or 750 m for VIIRS) product only).

The only way Cloud Fractions could be computed in L3 was through the 1km Cloud Mask Flags directly. So the Cloud Fraction computed in L3 CLDPROP were from 1km sampled data (instead of 5km averaged data as the case in MOD08). This could lead to some interesting (and possibly noticeable) differences between Cloud_Fraction in MOD08 (derived from 5x5 km averaged L2 data) vs CLDPROP (derived from 1km L2 data sampled at 5km). One might theorize that the older MODIS Standard MOD08 would produce slightly more representative Cloud Fraction from Cloud Mask results since the entire 5x5 km L2 region is being queried, instead of a single 1km pixel sample.

8.2. Cloud Mask Cloud Fraction Pixels Counts: MOD08 vs. CLDPROP

Another difference in the statistics for Cloud Fraction from Cloud Mask is noted in the Pixel Counts. In MODIS Standard MOD08, the Cloud Fraction Pixel Counts is the numerator of the fraction (the number of cloudy pixels). While in CLDPROP L3, the Cloud Fraction Pixel Counts is the denominator of the fraction (the total number of clear + cloudy pixels). This difference in the meaning of Pixel Counts for Cloud Fraction Groups results from the different way this quantity was calculated in MODIS Standard vs. Continuity.

If a user would like to see the numerator for Cloud Fraction in CLDPROP L3, simply multiply the Fraction (ranging from 0.0 to 1.0) by the Pixel Counts.

Note that this change in the meaning of Pixel Counts applies to all Cloud Fractions in CLDPROP L3, including those computed for Cloud Optical Property Retrievals (e.g.: Cloud_Retireval_Fraction_Liquid, etc.)

For all other types of Parameters (that are not Cloud Fraction), the Pixel Count has a more traditional meaning. That is it's the number of valid or successful L2 sampled retrievals for each particular Parameter.

8.3. View Zentih Angle cut-off for input L2 data into CLDPROP L3

There are significant differences in sensor swath geometry between MODIS and VIIRS, which can have profound impacts on the cloud products derived from each. The wider swath of VIIRS allows for greater sampling at all latitudes, removing orbital gaps in the tropics while increasing swath overlap at higher latitudes. However, known view-angle-dependent biases, such as artificially increasing cloud fraction towards scan edge or the increased likelihood of viewing the sides of clouds (with implications on cloud top, optical, and microphysical retrievals), are likely larger in these additional VIIRS pixels at the edge of the swath. Furthermore, the limited pixel size growth of the VIIRS M-bands towards the edge of scan also reduces the impact of sub-pixel cloud heterogeneity and 3D effects that increase as pixel size grows. Those effects have been shown to significantly impact the MODIS cloud optical/microphysical property retrievals under various conditions.

One way to mitigate these sensor swath geometry differences is to limit the L2 VIIRS data (passed to L3) to data having a View (or Sensor) Zenith Angle (VZA) ≤ 65.5°. This change impacts (mostly) the L3 VIIRS data and helps create a better match between MODIS L3 and VIIRS L3 in the Continuity Stream.

Note this VZA cutoff is also applied (by default) to MODIS Aqua data, since the same L3 algorithm and configuration is applied to all Instrument/Platform combinations in the Continuity data set record. However, this masking should have little to no effect on MODIS data at L3, since there is little to no MODIS data outside that set VZA range.

For VIIRS, the View (or Sensor) Zenith Angle actually ranges from 0.01 to 70.17 – so this L3 CLDPROP code change removes the outer 4.67 degrees of the Sensor Zenith Angle pixels from VIIRS L3 to better match MODIS L3.

Note that Scan Angle and View (Sensor) Zenith Angle are in fact different parameters. Scan Angle is defined at the sensor, i.e., the angle of the scan head (pixel detector) itself with respect to nadir (looking straight down). View (Sensor) Zenith Angle is defined at the retrieved surface (surface of the Earth or surface of the cloud), i.e., the angle between the line from the retrieved surface to the sensor and the line straight up (away from the center of the Earth) from the retrieved surface.

Due to the curvature of the Earth, the View (Sensor) Zenith Angle will always be larger than the Scan Angle, with differences increasing towards the edge of scan. See Figure 21. The VIIRS Scan Angle has a range of ± 56.28°, while the View (Sensor) Zenith Angle ranges from 0.01 to 70.17°.

An aside: the L2 CLDPROP development team reported that some help was needed to clarify what angle is actually reported in the geolocation file. Bottom line is that for both MODIS and VIIRS, the geolocation (L1B and L2) files report View Zenith Angle as the Sensor Zenith Angle (the "Sensor" part of that variable name, which might be misconstrued as referring to Scan Angle, was confusing initially). Now it has been clarified that View Zenith Angle (the better term) is the same as the Sensor Zenith Angle reported in the geolocation files.

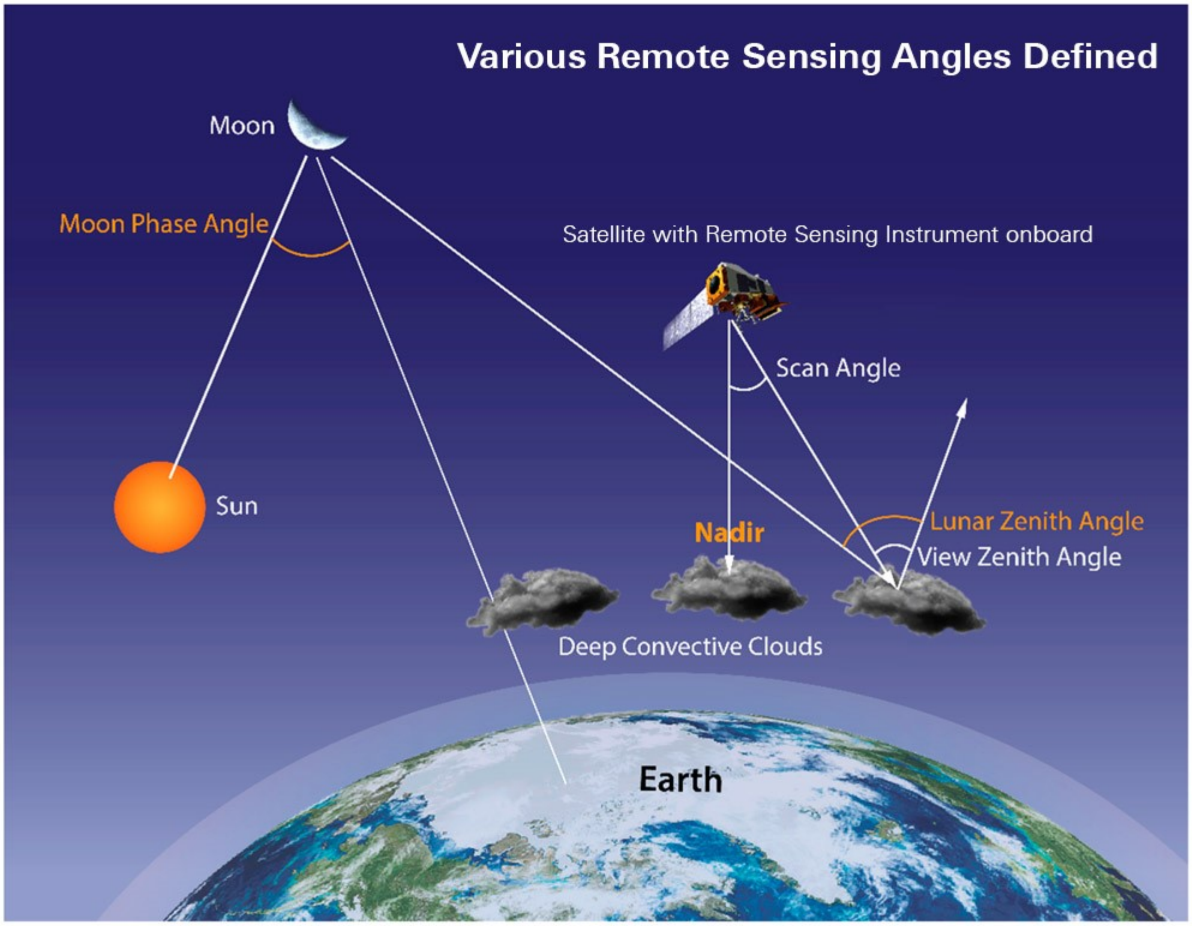


Figure 21. Abstract image (obviously not anywhere close to scale) providing a visual reference of various remote sensing angle defintions. The two key angles being discussed here are Scan Angle and View Zentih Angle. The L3 CLDPROP code limits L2 input to pixels where View Zenith Angle ≤ 65.5°, which primarily impacts VIIRS data.

8.4. Monthly Cloud Top Property (CTP) Weighting: MOD08 vs. CLDPROP

Users comparing CTP-related data in the monthly MODIS Continuity file (CLDPROP_M3) to the MODIS Standard data file (MOD08_M3) should be aware of a difference in how the monthly mean and standard deviation statistics were computed for all CTP-related parameters. The monthly MODIS Standard (MOD08_M3) product is using an *Unweighted Weighting Scheme* in computing Cloud Top Property related statistics. That is, monthly MODIS Standard (MOD08_M3) CTP-related statistics (e.g.: Cloud_Top_Temperature_Mean_Mean) is an unweighted *mean of the daily mean* without regard to pixel counts observed on each day. While the monthly Continuity (CLDPROP_M3) product is using a *Pixel Count Weighting Scheme* in computing CTP-related statistics (e.g.: Cloud_Top_Temperature, Mean). So there is a difference between how the CTP parameters are being computed in a MODIS Standard M3 file (unweighted) vs. a Continuity M3 file (pixel-count weighted).

8.5 CTP_Phase Array Masking

Note that a decision was made during the development of L3 CLDPROP to mask the **CTP_Phase** Histogram_Count arrays in L3 (see Table 8 in Section 7) with a *Cloud Mask Determined* T/F mask. This will allow Fill Values to enter that array and not skew the 0 (clear) counts. (Fill should be noted as -999 in L3 CTP_Phase array.) The masking array is called **Mask_CloudMaskDetermined** in the Pre-Yori file and used to mask the data in the YAML file. The L3 development team is expecting that this is the correct way to specify in order to properly separate clear from fill.

8.6 Simple Stats most users can ignore: Sum & Sum_Squares

There are five standard simple statistics (computed as a set) in almost all L3 CLDPROP Groups: Mean, Standard_Devidation, Pixel_Counts, Sum, and Sum_Squares. Users can generally ignore the last two statistics in that list (Sum and Sum_Squares) as they are generally not useful quantities to most users. However they are a required element in Yori, needed so that the Mean and Standard_Deviation statistic can be recomputed on the fly, as data is aggregated (spatially and temporally) in L3.

8.7 Pixel_Count Array Initialization: MOD08 vs. CLDPROP

Note that Pixel Count statistics in L3 CLDPROP (produced by the Yori System) are initialized with zero -- and not fill (missing) as was done for MODIS Standard MOD08. This means orbital gaps and day/night boundary regions will be shown as 0 and not fill in all count-related data/imagery. In other words, Pixel_Count images will not show (as clearly) data gap (missing data) regions (typically seen between orbital swaths in Daily images for MODIS and over the poles for day or night only data).

This statistic initialization rule also applies to histogram count and joint histogram count arrays – so basically all count arrays are initialized with zero (and not fill) in L3 CLDPROP. If a user wanted to show those missing data gaps on their Pixel_Count images, they would need to mask those images with the fill value from the Mean image. This visualization issue of fill vs. zero is less important for Histograms and Joint Histograms since those statistics tend not to be displayed on a geographic map -- so initializing with zero is less noticeable.

The L3 Development Team did attempt to get the UW Yori Development Team to change this procedure for initializing Pixel_Counts in Yori, but they seemed set on this decision saying that it made more sense for them to do it that way. Looking back on it now, it probably had a lot to do with how Yori is computing statistics on the fly and simplifying the Yori computational logic.

This issue does not impact the Mean and Standard Deviation statistics because those are initialized with fill-values (missing).

8.8 Histogram Bin Boundary definitions: MOD08 vs. CLDPROP

There is a slight bin boundary definition change between MODIS Standard and Continuity L3. For L3 Continuity CLDPROP, the first through the next-to-last (penultimate) histogram bin includes L2 data points that fall on the lower bin boundary. The last (ultimate) histogram bin includes L2 data points that fall on both the lower and the higher bin boundary.

For L3 MODIS Standard MOD08, the first histogram bin includes L2 data points that fall on both the lower and higher bin boundaries. All subsequent histogram bins include points that fall on the higher bin boundary.

For both streams, any L2 data point that falls outside the specified range of L3 histogram bin boundaries is not counted.

At first the L3 Development Team attempted to get the YORI developers to match the old MODIS Standard convention, but in the end it was decided it was only a minor issue that would not affect any science results, so it was left as is. It's unclear if there is a standard for this.

8.9. Changes for Uncertainty Information

This issue was discussed in Section 4.2.3.4. so refer to that section for more details. In CLDPROP L3 new Uncertainly Joint Histograms (JHisto_vs_Uncertainty) are created. These display pixel counts for percent (relative) L2 uncertainty in 21 joint histogram bins. The percent Uncertainly bin boundaries were taken from a suggestion by the L2 CLDPROP Development Team based on a number of case study analyses. The bin boundaries for the Uncertainty Axis in percent are: [0, 2, 4, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 150, 200]. These are used for all the JHisto_vs_Uncertainty arrays throughout the L3 CLDPROP file.

Please note that Relative Uncertainty (%) instead of Absolute Uncertainty (in the units of the parameter in question) were used in these new L3 joint histograms for two reasons: 1.) it allows for a consistent set of Uncertainty JH Bin Boundaries to be used across all L3 parameters streamlining both the coding, as well as the unpacking and interpretation by users, and 2.) it allows for a much faster operational run time in the Pre-Yori step.

For users to compute L3 grid-level Uncertainties based on these joint histograms, the relative uncertainties would then need to be post-processed, converting the uncertainties from relative (%) to absolute, based on the midpoint values of each bin -- and then run through a more complicated equation at the 1x1 degree L3 grid level. Details on a possible method to compute L3 grid uncertainties that was used in MODIS Standard L3 is outlined in Appendix C.

8.10. Screening occasionally bad L2 CER data < 4.0 microns

In June 2019, it was found that, very intermittantly, the L2 Cloud Optical Property Retrieval Algorithm was producing bad Cloud Effective Radius (CER) < 4.0 microns for liquid water and undetermined phase clouds. It was subsequently decided to mask (remove) these bad

L2 input CER data from L3 CLDPROP. Note that most of the L3 Cloud Optical Property Groups had to be masked for this issue. This includes all Liquid, Undetermined, and Combined cloud phase Groups for all flavors of retrievals (2.1, 1.6, 3.7 and 1.6-2.1). Note that Ice cloud phase retrievals did not have an issue. This (more global) masking at L3 was necessary in order to keep the total pixel counts the same between all Cloud Optical Property Parameters. Finally, the L3 *Cloud Retrieval Fraction* parameters required special logic in the Pre-Yori code that prevents clear-sky pixels from accidentally being masked out when the "CER ≥ 4.0 is True" mask is applied.

8.11. No Single Layer or Multi Layer Cloud Aggregations in L3 CLDPROP

There are no single layer (1L) or multi layer (ML) aggregations in L3 CLDPROP. It's impossible to do MODIS-style multilayer cloud detection with VIIRS, so it was dropped in the Continuity L2 Algorithm.

8.12.. Note about incorrect documentation in the L2 CLDPROP File

This note is related to the Cloud_Mask flags in L2 CLDPROP. The internal documentation for the Cloud Mask *Unobstructed FOV Flag* (written in the L2 CLDPROP file) states that Flag=1 means "Uncertain". Note that both the heritage MODIS Standard (MOD35_L2 & MOD06_L2) and the newer Continuity (CLDPROP) products are documented in this way. Rich Frey at UW (University of Wisconsin) confirmed with the primary author in August 2018 that Flag=1 should mean "Probably Cloudy" and not "Uncertain". "Uncertain" is too nebulous a word and ill-defined and did not convey enough information.

Further, it was confirmed at that time that the equation they recommend to compute Cloud_Fraction (from Cloud Mask) has not changed at any time during the MODIS data record. To compute Cloud Fraction from Cloud Mask, users should sum the counts in the first two L2 Cloud Mask QA Flag bins (confident cloudy and probably cloudy) and tag that as cloudy;

and then sum the last two bins (probably clear and confident clear) and tag that as clear; then compute the fraction.

Finally, note that this flag is correctly documented in the *Continuity Atmosphere QA Plan*, written in April 2019, and posted on the Atmosphere-Imager website at:

https://atmosphere-imager.gsfc.nasa.gov/continuity/documentation

8.13.. Day/Night Algorithm Cut-Off: MOD06/MOD08 vs. CLDPROP

The Day/Night separation for Cloud Top Parameter related parameters in MODIS Standard MOD06/MOD08 was based on the L2 Cloud Mask QA Day/Night Flag. Note that this Day/Night Flag is using Solar Zenith Angle ≤ 85 degrees as a daytime cutoff.

However for the L2 Continuity Cloud Top Properties algorithm, the daytime cutoff was changed from 85 to 80 degrees.

For Cloud Optical Property L2 CLDPROP products, the daytime cutoff was initially set (early on in development) to 81.3731 degrees, matching the cutoff used in MODIS Standard MOD06 Products; however by late 2018, it was decided to change that from 81.3731 to 80 degrees to match the Cloud Top Properties Continuity Algorithm. See Table 9.

By early 2019, L2 Cloud Optical Properties Team expressed a desire to eventually have the L2 Cloud Mask Team to change their Cloud_Mask QA Day/Night Flag to match the new day/night cutoff being used for Cloud Top Properties and Cloud Optical Properties (SZA ≤ 80°) -- however there is no formal plan to do that at the present time.

This means as long as L3 CLDPROP is using the Cloud_Mask Day/Night QA Flag cutoff (SZA ≤ 85°) to aggregate day and night Cloud Top Property related products in L3, some of the Cloud Top Property L3 Groups tagged "_Day" will have some nighttime pixels (that is, pixels that the Cloud Top Properties algorithm is tagging as night) included (mixed in) near the edge of the day/night boundary.

Since Cloud Optical Property (COP) Parameters are never aggregated as Day vs. Night (since the COP algorithm is only run in the daytime), this issue will not affect COP parameters.

Algorithm	**MODIS Standard Atmosphere** Day/Night Cut off	**Continuity Atmosphere** Day/Night Cut off
Cloud Mask Algorithm	Solar Zentih ≤ 85°	Solar Zentih ≤ 85°
Cloud Top Property Algorithm	Solar Zentih ≤ 85°	Solar Zentih ≤ 80°
Cloud Optical Property Algorithm	Solar Zentih ≤ 81.3731°	Solar Zentih ≤ 80°

Table 9. The Different ways the three Cloud Algorithm Teams (Cloud Mask, Cloud Top, and Cloud Optical) have defined the Day/Night Cut off for both the MODIS Standard Products (MOD06, MOD08), shown in the middle column; and for the later Continuity Products (CLDPROP), shown in the far right column. The Solar Zenith Angles shown in the table are what is needed to define daytime; everything else would fall into nighttime.

8.14. No Cloud_Fraction Joint Histograms possible in L3 CLDPROP

Note that it's impossible to do a Cloud_Fraction JHisto_vs_Pressure statistic, as was done in MOD08-MODIS, because there are no Cloud Fractions computed (in advance) in L2 CLDPROP. Cloud Fractions are not actually computed until L3.

8.15. File format tweaks to improve interaction with Visualization Tools (e.g.: Panoply)

Early on in the development of L3 CLDPROP products, the NetCDF4 files were not interacting nicely with Panoply (one of the most popular visualization and analysis tools) in terms of creating optimal image titles by default. The primary reason for this was the new Group/Variable format of L3 Continuity CLDPROP vs. the old stand-alone Scientific Data Set (SDS) format of L3 MODIS Standard MOD08.

When Panoply titles images from a NetCDF4 file with the Group/Variable structure, the Group information is ignored and instead Panoply uses information attached to the Variable only. In this paradigm, Panoply creates image titles based on the following list of items, any of which might be associated with a specific variable -- in descending order of priority: 1.) the *long_name* attribute, 2.) the *title* attribute, 3.) the *standard_name* attribute, and 4.) the variable's *simple name*. The first three items in the list are defined through the use of local attributes attached to the variable.

Option 1, the *long_name* attribute, which is, by default, attached to the Group as a group attribute in the L3 CLDPROP NetCDF4 file, was too wordy and long-winded to use as an image title, so we decided not to transfer (or pass-through) that string to a local attribute attached to variables in that Group (so that Panoply would "pick it up" when it read each variable). Option 4, the variable's *simple name*, was too short (too cryptic) with not enough information included -- it's simply the name of the variable (e.g.: Mean).

This left only two options on the table to remedy this short-coming. The *title* attribute (option 2) and the *standard-name* attribute (option 3).

The *title* attribute is described in the NetCDF4 User Guide as *a character array providing a succinct description of what is in the variable*. The *standard_name* attribute is described in the NetCDF4 User Guide as *a long descriptive name for the variable taken from a controlled vocabulary of variable names*.

Of these two remaining choices, we chose option 2, the ***title*** attribute, to solve our titling problems in Panoply. We made this choice for three primary reasons. First, the ***title*** attribute was a higher priority than the ***standard_name*** attribute in Panoply's internal rankng system – and we thought it was prudent to use the higher ranking vehicle. Second, we found the name of the keyword itself, "title", the most descriptive, since this whole process was done to fix how Panoply *titles* images from L3 CLDPROP files -- so why not use an attribute name that captures that meaning literally. (This also makes it easier to for users to figure out what that attribute means without added documentation). Third, when we read the meaning of the ***title*** attribute in the NetCDF User Guide, it used the key word *succinct* (meaning a concise and compact description). So a ***title*** local attribute is defined to be a shorter laconic string (while still defining the variable fully), and therefore felt it would best fit in the limited space available for most image titles, while retaining enough information to fully describe the variable.

Therefore, in our final production version of the L3 CLDPROP NetCDF4 file, an attribute called ***title*** is attached to **all** variables and provides information that can be passed to various visualization packages (e.g.: Panoply) telling the package how to explicitly title images produced from that variable. Under most circumstances, these ***title*** local attributes are a simple combination of the Group name and the Variable name, which matches fairly closely how images were generally titled for variables (statistics) imaged from MODIS Standard Products. This new ***title*** local attribute was implemented in Yori Software version 1.3.8 and later, which was launched on 9 July 2019, and is reflected in all L3 CLDPROP files produced after that date.

Note that custom software tools, manually written in Python, IDL, or other languages, by individual users, can be designed to do this sort of Group and Variable combining on the fly to make well-behaved image titles, however we were looking for a way to standardize how our files were going to pass titling information to pre-packaged commercial or standardized (widely distributed) visualization tools (like Panoply).

9.0. Using the newly redesigned Atmosphere-Imager web site

The original MODIS-Atmosphere web site (developed in 1999) was designed for MODIS Standard Products. This site was completely redesigned in 2018 (using the state-of-the-art Drupal framework) and adapted to include the new Continuity Products. (Screen-captures in Figures 21 through 25.) The redesigned website was renamed the **Atmosphere-Imager** (AI) website and can be viewed at: https://atmosphere-imager.gsfc.nasa.gov

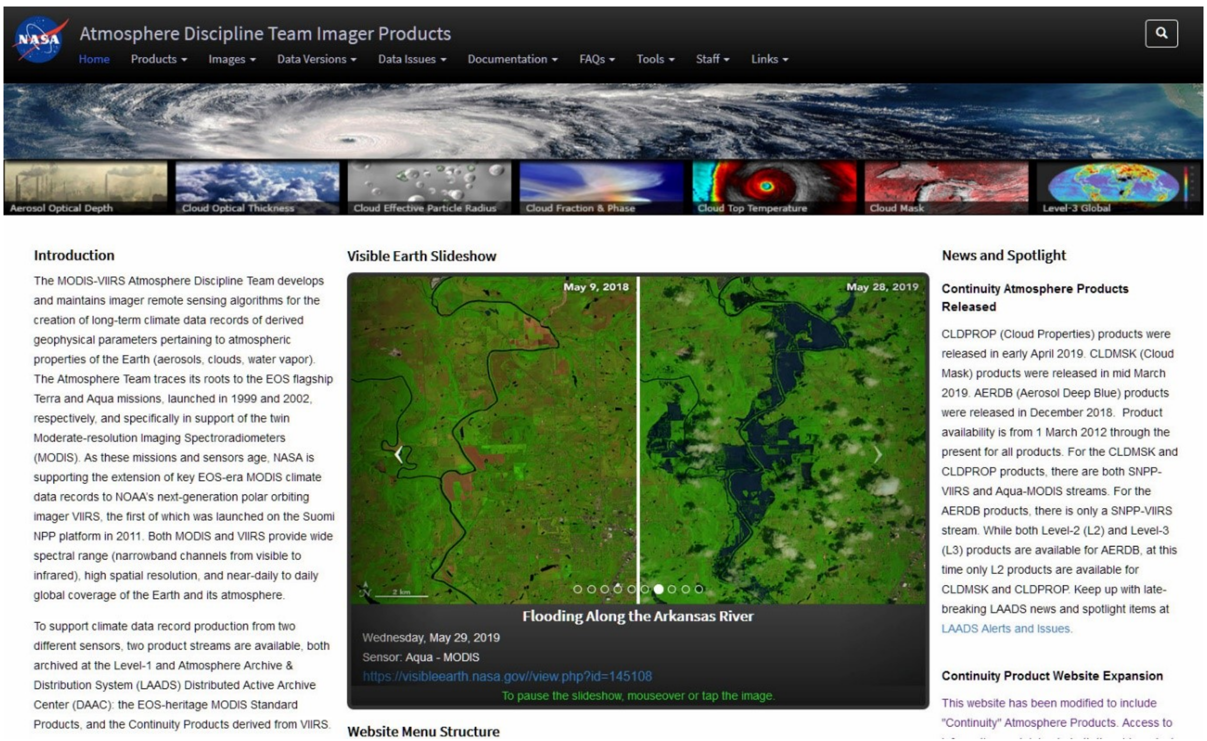


Figure 22. A capture of the new Atmosphere Imager website that was redesigned with a split navigation bar, allowing visitors to view both MODIS Standard content as well as new Continuity content.

The Atmosphere-Imager website has a new user-friendly navigation interface that can be used to view either heritage MODIS Standard content or newer Continuity content. This navigation *split* can be found if a visitor *pulls-down* some of the main topic links displayed at the top of all pages. The main topic links that have this navigation *split* are: 1.) Products, 2.) Images, 3.) Data Versions, 4.) Data Issues, 5.) Documentation, and 6.) FAQs. By selecting the "Continuity" option on any of these main topic pulldown menus, one branches into sections of the website geared towards these new Atmosphere Continuity Products.

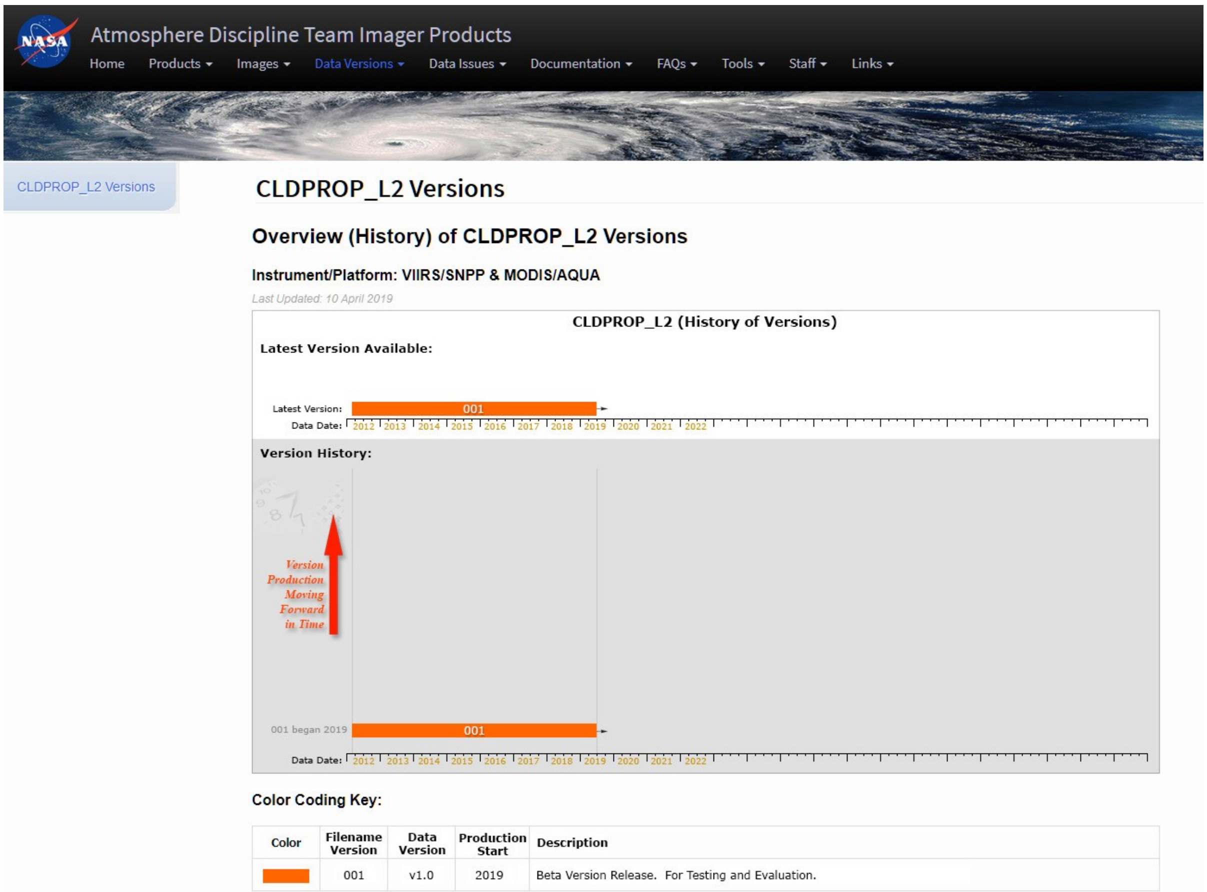
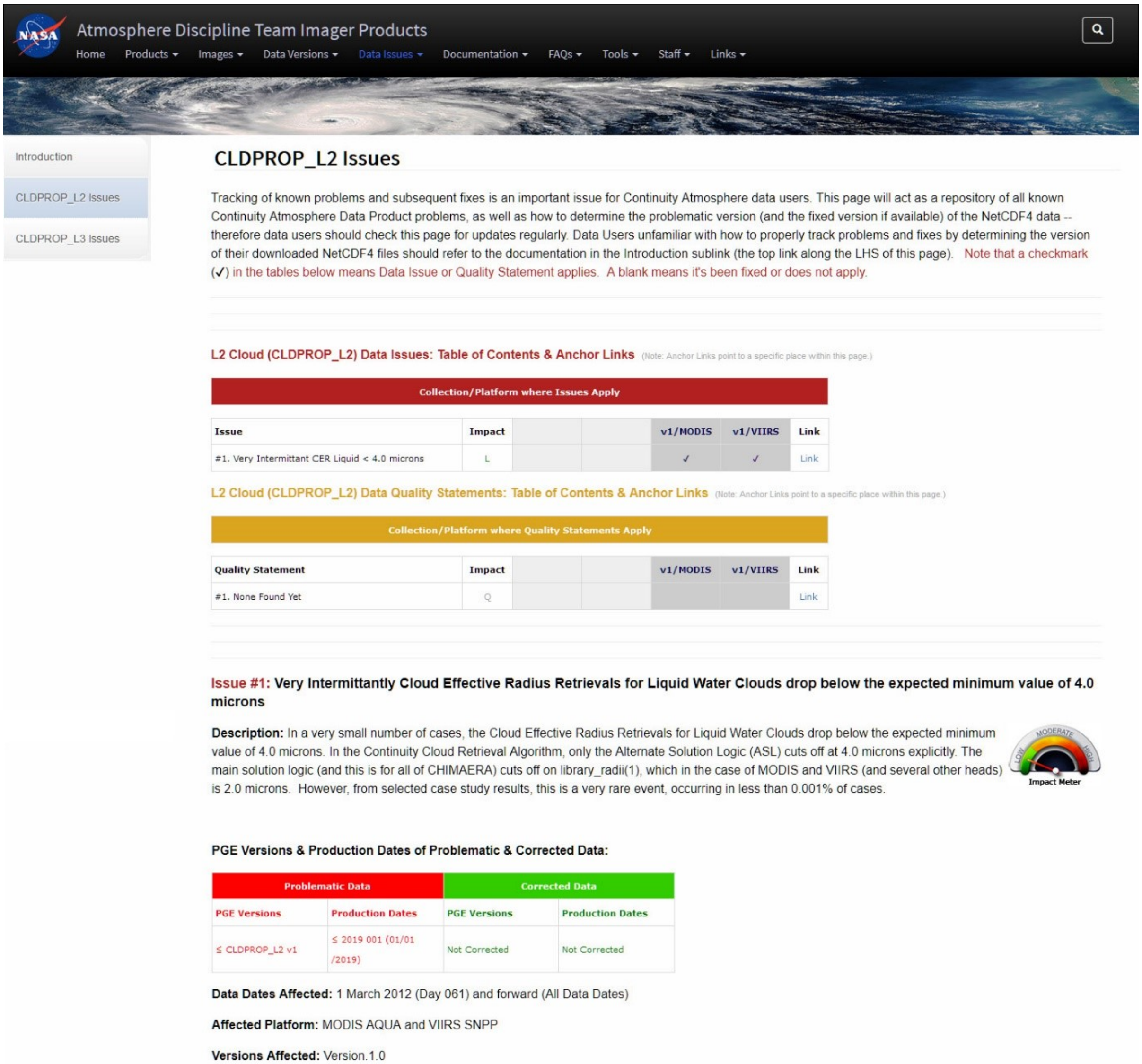


Figure 23. A capture of the Data Versions > Continuity > CLDPROP_L2 Versions page. New graphics were developed that show processing status as well as the history of older versions.



Atmosphere Discipline Team Imager Products

Home | Products ▾ | Images ▾ | Data Versions ▾ | Data Issues ▾ | Documentation ▾ | FAQs ▾ | Tools ▾ | Staff ▾ | Links ▾

Introduction

CLDPROP_L2 Issues

CLDPROP_L3 Issues

CLDPROP_L2 Issues

Tracking of known problems and subsequent fixes is an important issue for Continuity Atmosphere data users. This page will act as a repository of all known Continuity Atmosphere Data Product problems, as well as how to determine the problematic version (and the fixed version if available) of the NetCDF4 data -- therefore data users should check this page for updates regularly. Data Users unfamiliar with how to properly track problems and fixes by determining the version of their downloaded NetCDF4 files should refer to the documentation in the Introduction sublink (the top link along the LHS of this page). Note that a checkmark (✓) in the tables below means Data Issue or Quality Statement applies. A blank means it's been fixed or does not apply.

L2 Cloud (CLDPROP_L2) Data Issues: Table of Contents & Anchor Links (Note: Anchor Links point to a specific place within this page.)

Collection/Platform where Issues Apply						
Issue	**Impact**			**v1/MODIS**	**v1/VIIRS**	**Link**
#1. Very Intermittant CER Liquid < 4.0 microns	L			✓	✓	Link

L2 Cloud (CLDPROP_L2) Data Quality Statements: Table of Contents & Anchor Links (Note: Anchor Links point to a specific place within this page.)

Collection/Platform where Quality Statements Apply						
Quality Statement	**Impact**			**v1/MODIS**	**v1/VIIRS**	**Link**
#1. None Found Yet	Q					Link

Issue #1: Very Intermittantly Cloud Effective Radius Retrievals for Liquid Water Clouds drop below the expected minimum value of 4.0 microns

Description: In a very small number of cases, the Cloud Effective Radius Retrievals for Liquid Water Clouds drop below the expected minimum value of 4.0 microns. In the Continuity Cloud Retrieval Algorithm, only the Alternate Solution Logic (ASL) cuts off at 4.0 microns explicitly. The main solution logic (and this is for all of CHIMAERA) cuts off on library_radii(1), which in the case of MODIS and VIIRS (and several other heads) is 2.0 microns. However, from selected case study results, this is a very rare event, occurring in less than 0.001% of cases.

LOW MODERATE HIGH
Impact Meter

PGE Versions & Production Dates of Problematic & Corrected Data:

Problematic Data		Corrected Data	
PGE Versions	**Production Dates**	**PGE Versions**	**Production Dates**
≤ CLDPROP_L2 v1	≤ 2019 001 (01/01 /2019)	Not Corrected	Not Corrected

Data Dates Affected: 1 March 2012 (Day 061) and forward (All Data Dates)

Affected Platform: MODIS AQUA and VIIRS SNPP

Versions Affected: Version 1.0

Figure 24. A capture of the Data Issues > Continuity > CLDPROP_L2 Issues page. As problems or issues are discovered in the data, they are posted here to alert the user community. Also provided are fixes (if possible) as well as a graphical Impact Meter to give a quick overview as to whether an issue has Low, Medium, or High Impact.

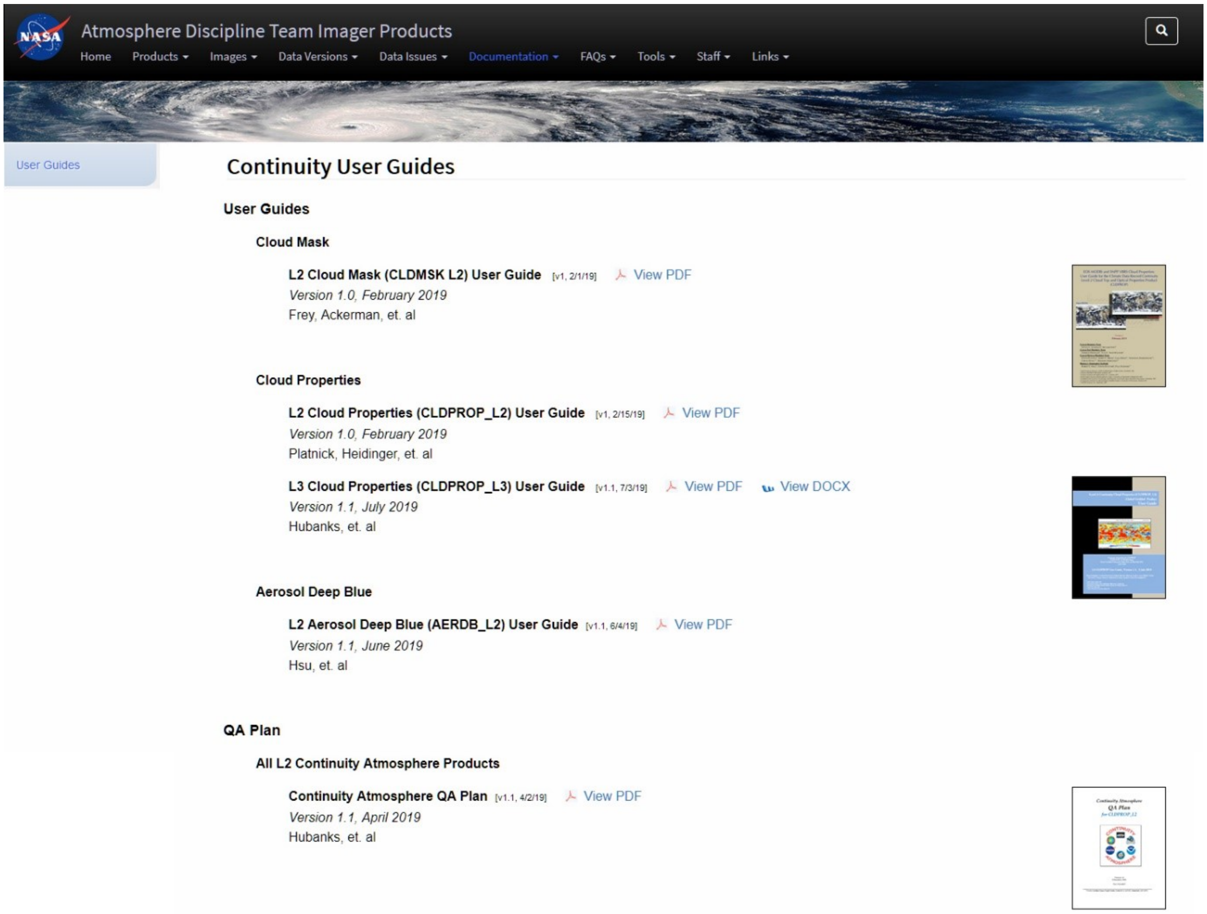


Figure 25. A capture of the Documentation > Continuity > User Guides page. Here, users can find guides, documents, and plans that help describe the new Continuity products and data.

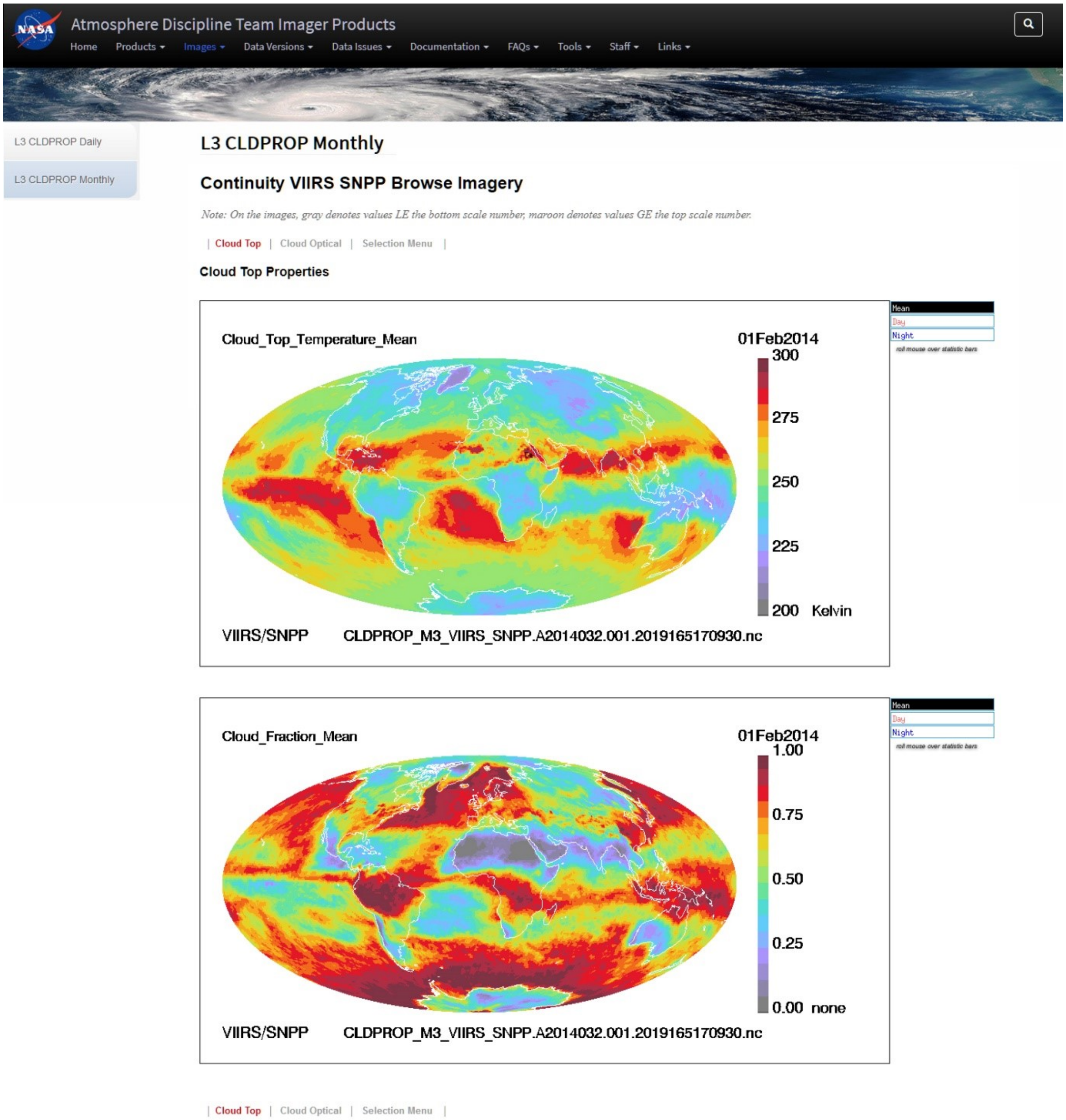


Figure 26. A capture of the Images > Continuity > L3 CLDPROP Monthly page. Here, users can find browse images for L3 CLDPROP Products. A JavaScript mouse-over feature allows one to view a number of different images in a single frame, allowing for quick (*flash)* a-b-c comparisons.

For L3 CLDPROP **Daily** products, images are only available in the native equal-angle latitude-longitude (rectangular) grid. For L3 CLDPROP **Monthly** products, images projected in both the native equal-angle latitude-longitude grid, as well as an equal-area Hammer-Aitoff grid are available.

10.0. Interpretation of Data: Frequently Asked Questions

Since the release of L3 MODIS Standard and Continuity Data Products, data users have asked the L3 development team and associated Atmosphere staff a number of questions. This section summarizes the most common questions and their answers.

10.1. Difference between Cloud Fraction (i) from Cloud Mask, and (ii) from Cloud Optical Property Retrievals. Formula to recover the total number of cloudy (or true) pixels, the fraction numerator, in L3 CLDPROP.

In order for users to understand the meaning of the two basic cloud fractions in L3 CLDPROP products, an understanding of how cloud fraction is defined and computed in each L3 cloud fraction parameter is needed. From the simplest perspective, cloud fraction at L3 is the number of cloudy L2 pixels (that fit pre-determined criteria, such as daytime only or liquid water clouds only) divided by the total number of non-fill L2 pixels within a 1×1° L3 grid box. The key detail is how each parameter defines a pixel as "cloudy" and what domain of pixels is used in the computation of the denominator.

There are two primary types of cloud fractions L3 CLDPROP files.

10.1.1. Cloud Fraction from Cloud Mask

The L3 cloud fraction that garners the most interest from Atmosphere data users is Cloud Fraction derived directly from the Cloud Mask. These L3 CLDPROP cloud mask cloud fractions have the Group names:

- Cloud_Fraction
- Cloud_Fraction_Day
- Cloud_Fraction_Night

The first parameter listed above contains both day and night retrievals, the second parameter contains daytime-only retrievals (solar zenith angle less than or equal to 85°), and the third parameter contains nighttime-only retrievals.

The cloud mask cloud fraction is computed in L3 using the Cloud Mask Status Flag and the Cloud Mask Cloudiness Flag, both a part of the Quality_Assurance SDS in L2 CLDPROP. See Table 10.

L2 QA Flag	Flag Value	Meaning
Cloud Mask Status Flag	0 1	Undetermined Determined
Cloud Mask Cloudiness Flag	0 1 2 3	Confident Cloudy (or Fill if Status Flag = 0) Probably Cloudy Probably Clear Confident Clear

Table 10. Two L2 Cloud Mask Flags used to compute the L3 Cloud Mask Cloud Fraction.

In the computation of the L3 cloud mask cloud fraction, the first two flags are assigned 100% cloudy and the last two flags 100% clear. Then in each 1x1 degree L3 grid, the mean L2 cloudiness is computed based on those results.

10.1.2. Cloud Fraction from Cloud Optical Property Retrievals

The second-most utilized L3 cloud fraction is the one derived from the Cloud Optical Properties retrieval. All optical property cloud fractions are computed for **daytime scenes only** (solar zenith angle ≤ 80°).

These L3 CLDPROP cloud optical property cloud fractions have the Group names:

- Cloud_ Retrieval_Fraction_Liquid
- Cloud_ Retrieval_Fraction_Ice
- Cloud_ Retrieval_Fraction_Undetermined
- Cloud_Retrieval_Fraction_Combined

The first parameter represents the cloud fraction for the liquid water cloud phase only; the second, ice phase clouds only; the third, undetermined phase clouds only; and the forth, combined (all) cloud phase clouds.

The optical property cloud fraction is computed in L3 using the Primary Cloud Retrieval Phase Flag and the Primary Cloud Retrieval Outcome Flag, both a part of the Quality_Assurance SDS in L2 CLDPROP. See Table 11.

Every sampled L2 grid point that has a Primary Cloud Retrieval Outcome Flag = 1 (Retrieval Successful) and a Primary Cloud Retrieval Phase Flag of 2 (Liquid Water Cloud), 3 (Ice Cloud), or 4 (Undetermined Phase Cloud) are taken as 100% cloudy for the cloud phase category in question. Then in each 1x1 degree L3 grid, the mean L2 cloudiness is computed based on those results.

L2 QA Flag	Flag Value	Meaning
Primary Cloud Retrieval Phase Flag	0 1 2 3 4	Cloud Mask Undetermined (Missing or Fill) Not Processed (Typically Clear) Liquid Water Cloud Ice Cloud Undetermined Phase Cloud
Primary Cloud Retrieval Outcome Flag	0 1	Retrieval Not Attempted or Unsuccessful Retrieval Successful

Table 11. Two L2 Quality Assurance Flags used to compute the L3 Cloud Optical Properties Cloud Fraction.

10.1.3. Formula to recover the total number of cloudy (or true) pixels in L3 CLDPROP

To retrieve the numerator of the cloud fraction, that is, the number of cloudy (or true) pixels (the fraction numerator) in L3 CLDPROP fraction groups, simply multiply the Pixel_Counts by the Mean (Fraction) in the particular cloud fraction group under consideration.

10.2. Meaning of Undetermined and Combined cloud phases

The undetermined cloud phase means the cloud optical properties retrieval algorithm could not make a determination of the cloud phase (liquid water or ice). This may have been caused by viewing anomalies in the retrieval (sunglint), contamination of the scene by aerosol, or a multi-layer cloud with mixed phases (e.g., thin cirrus overlying liquid water clouds). For these undetermined retrievals the liquid water libraries are used in the cloud optical properties retrievals, but the retrievals are considered to be of lower confidence (and quality) than those that are placed in one of the other primary phase categories (liquid water and ice).

The combined phase is simply a combination of all cloud phase categories: liquid water, ice, and undetermined.

10.3. Meaning of Partly Cloudy (PCL) Cloud Optical Property parameters.

There are a number of PCL (Partly Cloudy) Cloud Optical Property parameters in L3 CLDPROP files. They always have the string "_PCL" in the Group name.

These are slightly less reliable than the regular cloudy retrievals, therefore they were separated into a stand-alone SDSs so that users could decide either to mix them in with the regular retrievals or exclude them.

10.4. Best way to display 1D (marginal) histogram data

A total of 78 Groups in the L3 CLDPROP product files have marginal (1D) histogram data. (For a summary of Groups (Parameters) with 1D marginal histogram data defined, see Table 8 in section 7.0. For a summary of the histogram boundaries for all parameters, see Appendix B.)

One way to display 1D histogram data is by using a series of rectangular bars whose two dimensions represent (i) the bin size and (ii) the histogram value. The histogram value plotted can either be pure counts or a normalized probability density function (PDF).

Figure 27 shows a marginal histogram of counts for liquid water cloud effective particle radius pixels over ocean only for June 2005 as observed by the Aqua MODIS instrument. The bin boundaries are on the x-axis and the height of each bar represents the total L2 pixel counts (sampled) in each bin. The visual discontinuity in counts (vertical bar heights) in Figure 27, starting at the bin boundary of 20 μm, is due to the change of bin widths (going from 1 μm to 2 μm bins).

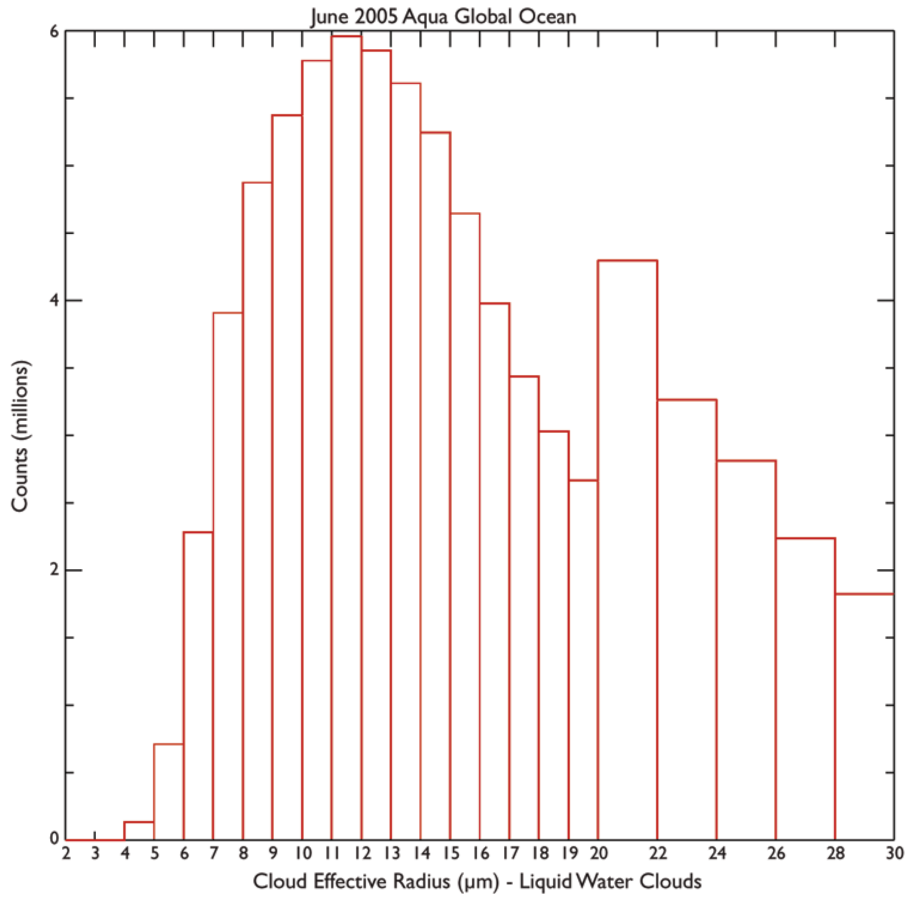


Figure 27. Marginal Histogram of L2 Pixel Counts (sampled) for Liquid Water Cloud Effective Radius during June 2005 (daytime only) for Global Ocean data from MODIS Standard Aqua/MODIS.

Users should keep in mind that one can plot “counts” (which is how the data are stored in the L3 HDF file) in each bin; or normalize the data by taking into account the bin sizes and plot “normalized probability” in each bin. This normalized probability calculation is performed as follows:

$$\text{Normalized Probability} = (\text{bin\_counts}) / (\text{bin\_width} * \text{total\_counts}) \qquad (4)$$

Figure 28 shows the same marginal histogram except plotted as a normalized probability density function (PDF). In this plot the double-wide bins are taken into account, so the heights of the vertical bars starting at 20 µm are half as high as those in Figure 27.

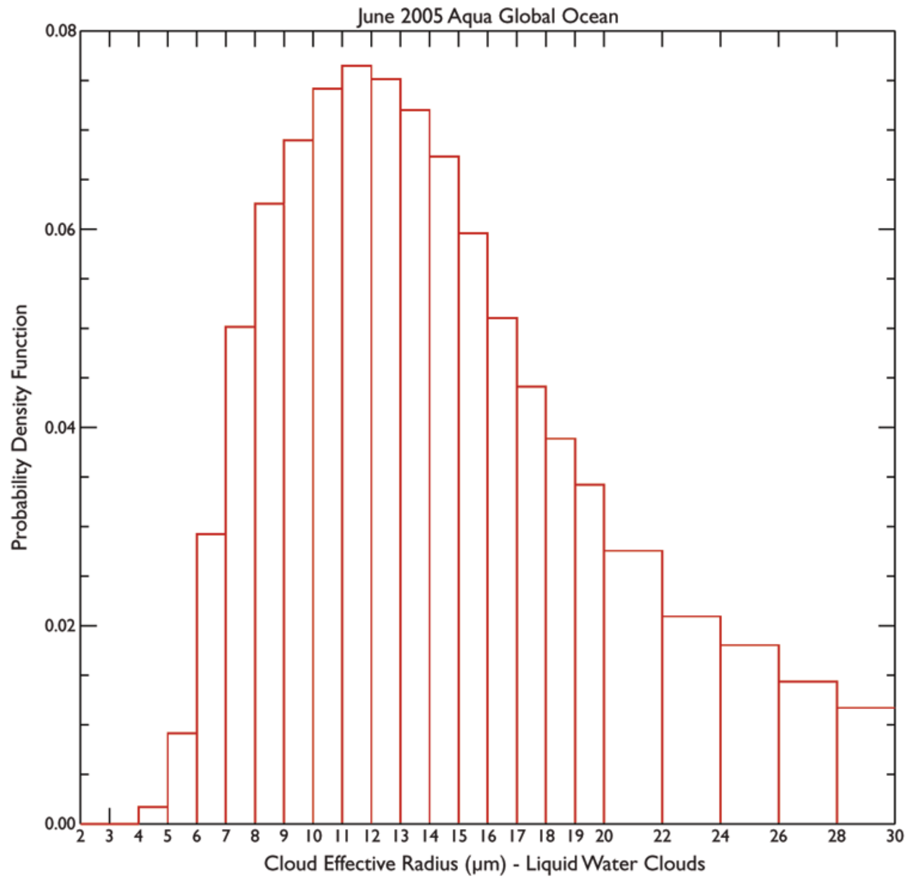


Figure 28. Marginal Histogram of Normalized Probability Density Function (PDF) (sampled) for Liquid Water Cloud Effective Radius during June 2005 (daytime only) for Global Ocean data from Aqua/MODIS.

For a normalized one-dimensional histogram plot, if one calculates the (size of bin) × (PDF value of bin) then an "area of the rectangle" calculation is actually being performed. When one sums all the rectangle areas, one ends up with the area (or integral) under the 'curve' of 1.0 or 100%.

For example, the peak PDF histogram bin value shown in Figure 45 is 0.076. (This occurs in the tenth bin, which corresponds to 11 μm < r_e ≤ 12 μm.) This means that 7.6% of the total area of the entire plot fell in this bin. This can also be interpreted as the probability of any one pixel falling in this peak histogram bin is 7.6%. If one performs this calculation for every bin (rectangle), and sums them, one ends up with 1.0 or 100%.

10.5. Best way to display 2D joint histogram data

Common ways to display Joint Histogram data are (i) 3D lego plots, (ii) smoothed contour plots, and (iii) color-coded histogram bin plots.

Lego plots (Figure 29) can be made by some graphics packages; however it's often difficult to read the exact height of each lego block, and some (or most) viewing orientations may cause some blocks to be hidden by larger blocks in front of them.

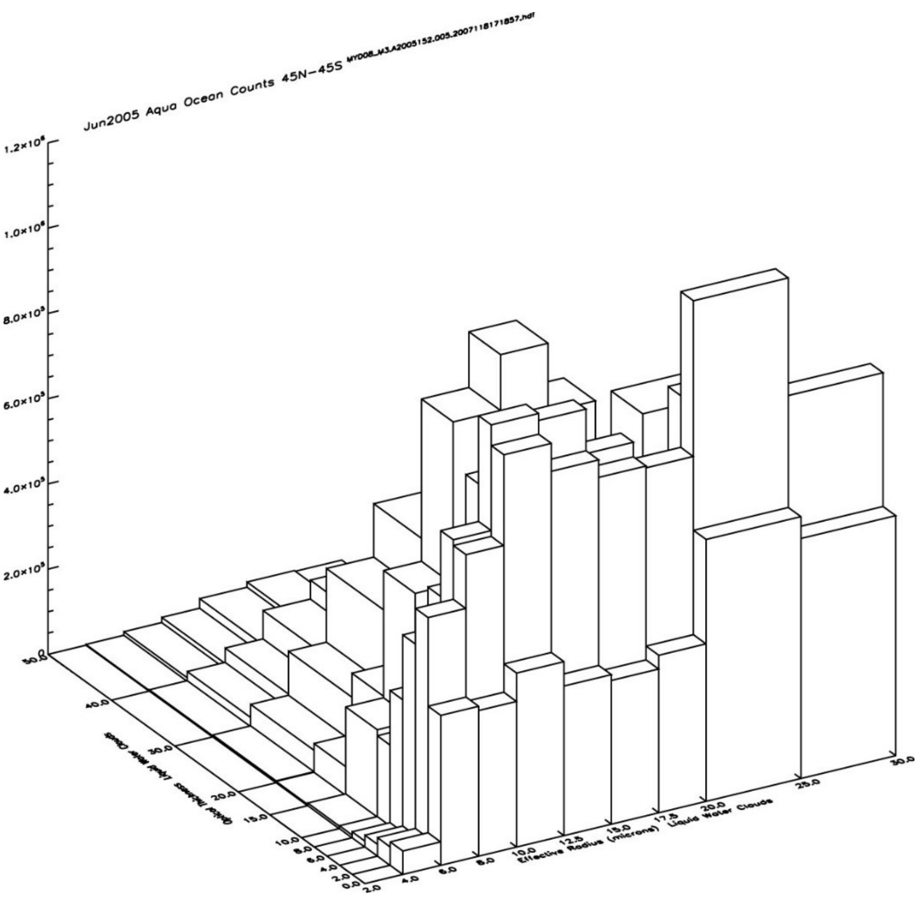


Figure 29. A June 2005 MYD08_M3 Counts Joint Histogram of cloud optical thickness (y-axis) vs. cloud effective radius (x-axis) for liquid water clouds displayed as a "3D lego plot" with post-processing to limit the data to ocean-only L3 grid cells that range from 45°N to 45°S. The top bin of cloud optical thickness from 50 to 100 was chopped off. The height of each Lego bar represents the number of counts in each bin. It is often difficult to impossible to orient lego plots to make all bins visible.

Smoothed contour plots (Figure 30) are useful as they allow quick visual interpretation of data (without an intimate knowledge of the color bar scale) and therefore lend themselves well to time-series animations, where the time to view each joint histogram movie frame is short. However, smoothing options can be difficult to fine-tune and the result is always a plot that shows a distorted (smoothed) view of the actual data.

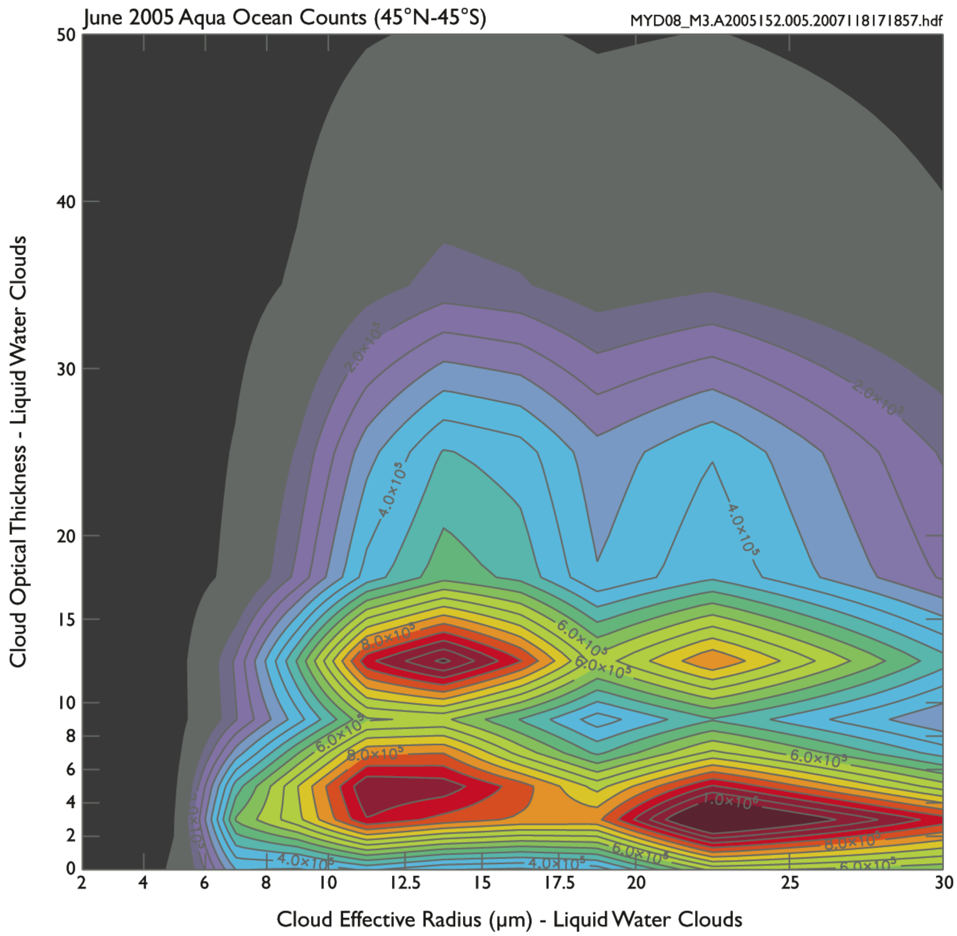


Figure 30. A June 2005 MYD08_M3 Counts Joint Histogram of cloud optical thickness (y-axis) vs. cloud effective radius (x-axis) for liquid water clouds displayed as a "colored contour plot" with post-processing to limit the data to ocean-only L3 grid cells that range from 45°N to 45°S. The top bin of cloud optical thickness from 50 to 100 was chopped off. The contour colors represent the number of counts in each bin (low is grey, high is red). Contour plots show a distorted (smoothed) view of the data stored in the joint histogram.

The third option, color-coded histogram bin plots (Figure 31), work the best in most cases and have few drawbacks; however some graphics packages cannot produce these plots without expert knowledge of the language and some user programming. The pros of this final method are there is no distortion (smoothing) of data in the x-y plane (as is the case with smoothed contour plots) and all cells (bins) can be viewed without any visual obstruction (as is the case with lego plots). Figures 28, 29, and 30 show identical MODIS L3 joint histogram counts data plotted using these three described techniques.

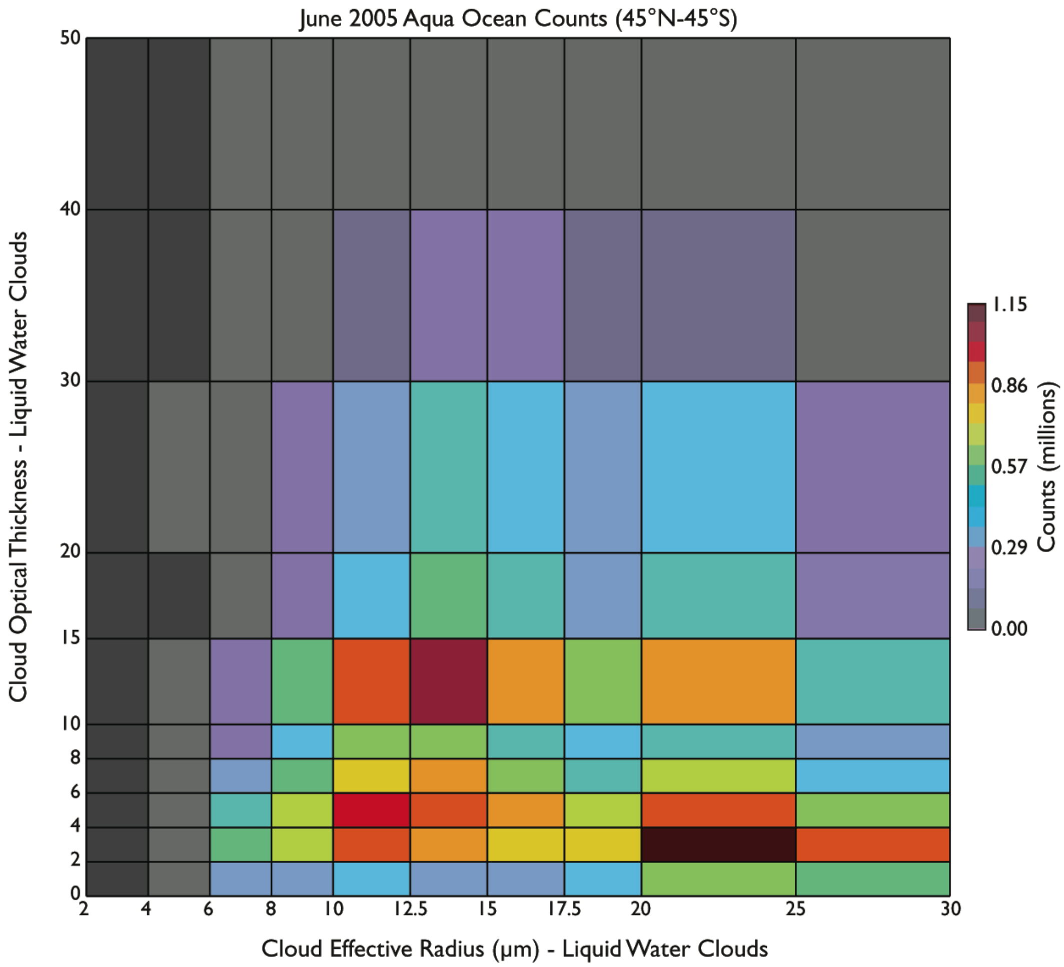


Figure 31. A June 2005 MYD08_M3 Counts Joint Histogram of cloud optical thickness (y-axis) vs. cloud effective radius (x-axis) for liquid water clouds displayed as a "colored histogram bin plot" with post-processing to limit the data to ocean-only L3 grid cells that range from 45°N to 45°S. The top bin of cloud optical thickness from 50 to 100 was chopped off. The bin colors represent the number of counts in each bin (low is grey, high is red).

For optimal display, it's best to have the graphics package print tick marks and labels at the exact histogram bin boundaries on both axes, so that the bin boundaries and sizes are clear to the viewer. These bin boundaries can be obtained from local attributes attached to each Joint Histogram variable (statistic) within the L3 CLDPROP file or read manually from the CDL file specification available on the Atmosphere-Imager web site at:

https://atmosphere-imager.gsfc.nasa.gov/continuity/products/cloud-properties-l3/file-spec

They are also provided in Appendix A and B of this User Guide for convenience.

Since all L3 joint histograms are stored as 4D arrays (Lat, Lon, Parameter1Bin, Parameter2Bin), MODIS data users can read (and view) a unique joint histogram for every L3 1° × 1° grid cell. This allows users to easily perform post-processing to narrow the application of the joint histogram to specific global regions to show more focused scientific results.

Users can apply a latitude/longitude screen to the 1°×1° gridded histograms so a newly computed (summed) joint histogram applies to a specified range of latitudes and longitudes only.

Users can also apply land-only or ocean-only masks when summing individual 1° × 1° gridded histograms so the newly summed joint histogram applies to land-only or ocean-only regions.

Users might also sometimes find it advantageous to delete (remove) the highest bin along one or both data axes (which typically have a large data range and few counts) when displaying joint histograms in order to show more detail in other more scientifically relevant bins.

Another item to keep in mind is one can plot “counts” (which is how the data are stored in the L3 HDF file) in each bin; or sometimes it is more useful to normalize the data by taking into account the bin sizes and then plot “normalized probability” in each bin. This normalized probability calculation is performed as follows:

$$\text{Normalized Probability} = (\text{bin\_box\_counts}) \;/\; (\text{bin\_box\_area} * \text{total\_counts}) \tag{5}$$

Converting the counts to normalized probabilities removes the visual anomalies that occur when comparing bins of different sizes in joint histogram plots. Figure 32 shows how the representation in Figure 31 changes when going from raw counts to normalized probability (where an adjustment is made for bin sizes). It’s clear that normalizing the data can really change one’s perspective of the results.

Finally, some ask, what do the Probability Density Function (PDF) numbers computed for each histogram bin in Figure 32 actually (physically) represent? If a normalized one-dimensional histogram plot means the area under the curve equals one; then a normalized joint histogram PDF plot means the volume under the surface equals one. (The surface being defined as z-axis heights or PDF values in each bin.) If one calculates the (area of bin) x (height of bin) or, alternatively (area of bin) × (PDF value of bin) then a "volume of the block" calculation is actually being performed. When one sums all the block volumes, one ends up with the volume under the surface, which for the normalized JPDF surface is 1.0 or 100%.

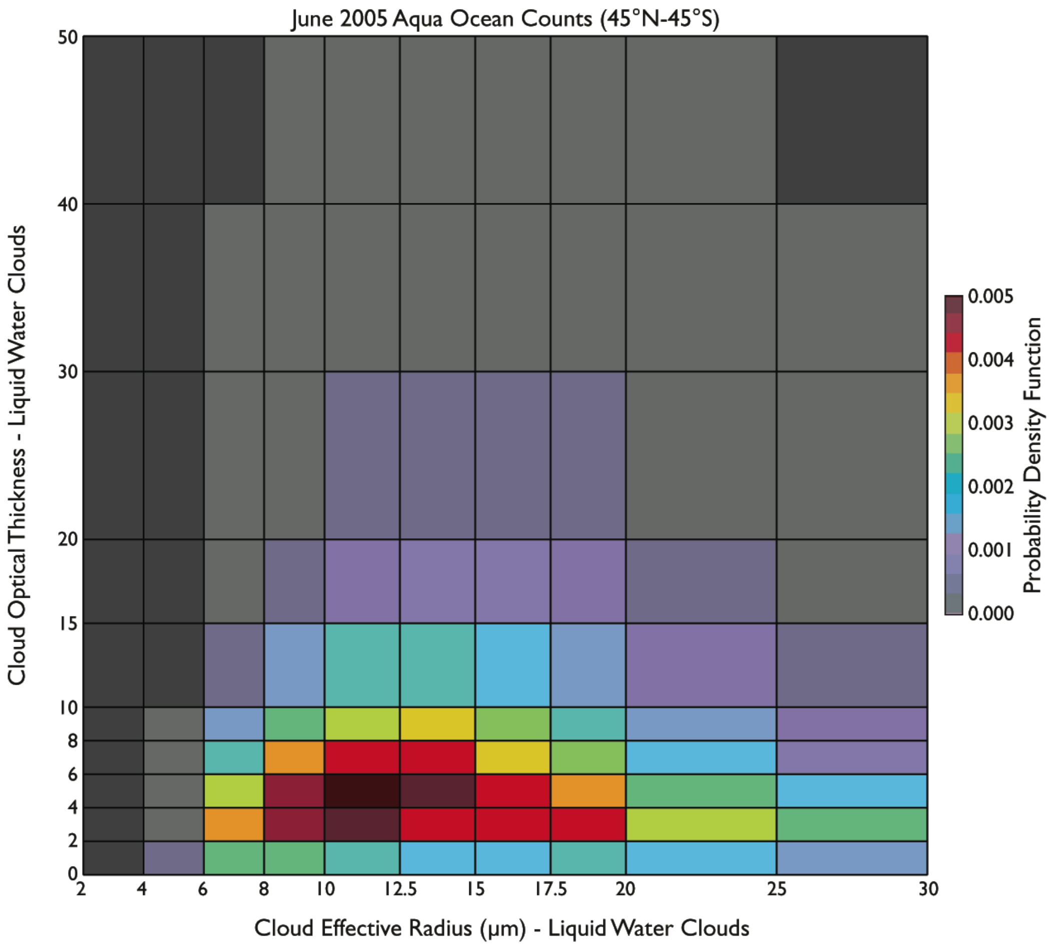


Figure 32. A June 2005 MYD08_M3 Normalized Probability Density Function (PDF) Joint Histogram of Cloud Optical Thickness (y-axis) vs. Cloud Effective Radius (x-axis) for Liquid Water Clouds displayed as a "colored histogram bin plot" with post-processing to limit the data to Ocean-only L3 grid cells that range from 45N to 45S. The top bin of Cloud Optical Thickness from 50 to 100 was removed. The bin colors represent the PDF in each bin (low probability is grey, high probability is red).

For example, the peak PDF histogram bin value shown in Figure 32 is 0.005. If you take this number and multiply by the area of the bin ($2.5 \times 2.0 = 5.0$), one gets a bin (block) volume of 0.025. This means that 2.5% of the total volume under the surface of the entire plot fell in this bin (block). This can also be interpreted as the probability of any one pixel falling in this peak joint histogram bin box is 2.5%. If one performs this calculation for every bin (block), and sums them, one ends up with 1.0 or 100%.

Note that for the joint histogram in Figures 28 through 31, the top bin ($50 <$ Optical Thickness ≤ 100) was cut off in order to show (allow) more visual detail in the remaining bins. In order to get the proper summed value of 1.0 (100%), one would need to include this deleted bin in the calculation.

11.0. References

Cao, C., X. Xiong, R. Wolfe, F. DeLuccia, Q. Liu, S. Blonski, G. Lin, M. Nishihama, D. Pogorzala, H. Oudrari, and D. Hillger (2013), *Visible Infrared Imaging Radiometer Suite (VIIRS) Sensor Data Record (SDR) User's Guide*, NOAA Technical Report NESDIS 142A, 49 pp., U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service.

Cho, H.-M., Z. Zhang, K. Meyer, M. Lebsock, S. Platnick, A. S. Ackerman, L. Di Girolamo, L. C.-Labonnote, C. Cornet, J. Riedi, and R. E. Holz (2015), Frequency and causes of failed MODIS cloud property retrievals for liquid phase clouds over global oceans. *J. Geophys. Res.*, 120, 4132-4154, doi:10.1002/2015JD023161.

Justice C.O., E. Vermote, J. Privette J., and A. Sei (2011), The Evolution of U.S. Moderate Resolution Optical Land Remote Sensing from AVHRR to VIIRS. *Land Remote Sensing and Global Environmental Change,* B. Ramachandran, C. Justice, and M. Abrams, Eds., Remote Sensing and Digital Image Processing, vol. 11. Springer, New York, NY., 781-806.

Oreopoulos, L., 2005: The impact of subsampling on MODIS Level-3 statistics of cloud optical thickness and effective radius. *IEEE Trans. Geosci. Remote Sens.*, **43**, 366–373.

Oreopoulos, L., R. Cahalan, and S. Platnick, 2007: The plane-parallel albedo bias of liquid clouds from MODIS observations. *J. Climate*, **20**, 5114–5125.

Wielicki, B. A. et al. (2013), Achieving climate change Absolute accuracy in orbit, *Bull. Amer. Met. Soc.*, 94(10), 1519–1539, doi:10.1175/BAMS-D-12-00149.1.

Zhang, Z., and S. Platnick (2011), An assessment of differences between cloud effective particle radius for marine water clouds from three MODIS spectral bands. *J. Geophys. Res.*, 116, D20215, doi:10.1029/2011JD016216.

Zhang, Z., A. S. Ackerman, G. Feingold, S. Platnick, R. Pincus, and H. Xue (2012), Effects of cloud horizontal inhomogeneity and drizzle on remote sensing of cloud droplet effective radius: Case studies based on large-eddy simulations. *J. Geophys. Res.,* 117, D19208, doi:10.1029/2012JD017655.

Appendix A:

Histogram Statistics
&
Bin Boundaries

Histogram Statistics and Bin Boundaries

Identical in Daily & Monthly Products

Cloud Top Properties (Day & Night)

Parameter	Bin Boundaries *	Bins	Units
Cloud_Top_Pressure Cloud_Top_Pressure_Day Cloud_Top_Pressure_Night	0, 80, 200, 320, 440, 560, 680, 800, 920, 1040, 1100	10	hPa (mb)
Cloud_Top_Temperature Cloud_Top_Temperature_Day Cloud_Top_Temperature_Night	150, 180, 190, 200, 210, 220, 225, 230, 235, 240, 245, 250, 255, 260, 265, 270, 275, 280, 285, 290, 320	20	degrees kelvin (K)
Cloud_Top_Height Cloud_Top_Height_Day Cloud_Top_Height_Night	0, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10000, 11000, 12000, 13000, 14000, 15000, 16000, 17000, 18000	18	meters
Cloud_Effective_Emissivity Cloud_Effective_Emissivity_Day Cloud_Effective_Emissivity_Night	0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 1.0	11	none
Cloud_Mask Cloud_Mask_Day Cloud_Mask_Night	-0.5, 0.5, 1.5, 2.5, 3.5 0 = Confident Cloudy 1 = Probably Cloudy 2 = Probably Clear 3 = Confident Clear	4	none
CTP_Phase CTP_Phase_Day CTP_Phase_Night	-0.5, 0.5, 1.5, 2.5, 3.5, 6.5 0 = Clear 1 = Liquid Water Cloud Phase 2 = Ice Cloud Phase 3 = Mixed Cloud Phase (Always 0 counts) 6 = Undetermined Cloud Phase (Always 0)	5	none

Cloud Optical Properties (Day Only)

Parameter	Bin Boundaries *	Bins	Units
Cloud_Optical_Thickness_Liquid Cloud_Optical_Thickness_PCL_Liquid Cloud_Optical_Thickness_16_Liquid Cloud_Optical_Thickness_16_PCL_Liquid Cloud_Optical_Thickness_37_Liquid Cloud_Optical_Thickness_37_PCL_Liquid Cloud_Optical_Thickness_1621_Liquid Cloud_Optical_Thickness_1621_PCL_Liquid	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50, 60, 70, 80, 90, 100, 150	46	none
Cloud_Optical_Thickness_Ice Cloud_Optical_Thickness_PCL_Ice Cloud_Optical_Thickness_16_Ice Cloud_Optical_Thickness_16_PCL_Ice Cloud_Optical_Thickness_37_Ice Cloud_Optical_Thickness_37_PCL_Ice	0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100, 150	31	none

Cloud_Optical_Thickness_1621_Ice Cloud_Optical_Thickness_1621_PCL_Ice			
Cloud_Optical_Thickness_Undetermined Cloud_Optical_Thickness_PCL_Undetermined	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50, 60, 70, 80, 90, 100, 150	46	none
Cloud_Optical_Thickness_Combined Cloud_Optical_Thickness_PCL_Combined	0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 150	41	none
COP_Phase_Cloudy	1.5, 2.5, 3.5, 4.5 2 = Liquid Water Cloud Phase 3 = Ice Cloud Phase 4 = Undetermined Cloud Phase Regular Cloudy (CLDY) Retrievals Only. Successful + Failed Retrievals for all. CSR = 0	3	none
COP_Phase_Partly_Cloudy	1.5, 2.5, 3.5, 4.5 2 = Liquid Water Cloud Phase (PCL) 3 = Ice Cloud Phase (PCL) 4 = Undetermined Cloud Phase (PCL) Partly Cloudy (PCL) Retrievals Only Successful + Failed Retrievals for all. CSR = 1 or 3	3	none
COP_Phase_CloudMaskClear	0.5, 1.5 1 = Cloud Mask Clear CSR = 0	1	none
COP_Phase_RestoredToClear	0.5, 1.5 1 = Restored To Clear CSR = 2	1	none

Cloud Optical Properties (continued)

Parameter	Bin Boundaries *	Bins	Units
Cloud_Effective_Radius_Liquid Cloud_Effective_Radius_PCL_Liquid Cloud_Effective_Radius_16_Liquid Cloud_Effective_Radius_16_PCL_Liquid Cloud_Effective_Radius_37_Liquid Cloud_Effective_Radius_37_PCL_Liquid Cloud_Effective_Radius_1621_Liquid Cloud_Effective_Radius_1621_PCL_Liquid	4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 24, 26, 28, 30	21	µm
Cloud_Effective_Radius_Ice Cloud_Effective_Radius_PCL_Ice Cloud_Effective_Radius_16_Ice Cloud_Effective_Radius_16_PCL_Ice Cloud_Effective_Radius_37_Ice Cloud_Effective_Radius_37_PCL_Ice Cloud_Effective_Radius_1621_Ice Cloud_Effective_Radius_1621_PCL_Ice	5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60	11	µm
Cloud_Effective_Radius_Undetermined Cloud_Effective_Radius_PCL_Undetermined	4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 24, 26, 28, 30	21	µm
Cloud_Water_Path_Liquid Cloud_Water_Path_PCL_Liquid Cloud_Water_Path_16_Liquid Cloud_Water_Path_16_PCL_Liquid Cloud_Water_Path_37_Liquid Cloud_Water_Path_37_PCL_Liquid Cloud_Water_Path_1621_Liquid Cloud_Water_Path_1621_PCL_Liquid	0, 10, 20, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 1000, 2000, 3000	15	$g\ m^{-2}$
Cloud_Water_Path_Ice Cloud_Water_Path_PCL_Ice Cloud_Water_Path_16_Ice Cloud_Water_Path_16_PCL_Ice Cloud_Water_Path_37_Ice Cloud_Water_Path_37_PCL_Ice Cloud_Water_Path_1621_Ice Cloud_Water_Path_1621_PCL_Ice	0, 10, 20, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 1000, 2000, 4000, 6000	16	$g\ m^{-2}$
Cloud_Water_Path_Undetermined Cloud_Water_Path_PCL_Undetermined	0, 10, 20, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 1000, 2000, 3000	15	$g\ m^{-2}$

* Bin Boundary Handling: For L3 CLDPROP Joint Histograms, the first through the next to last histogram bin includes L2 pixel values equal to the lower bin boundary. The **last bin** includes L2 pixel values equal to both the lower and the higher bin boundary. This is slightly different from MODIS Standard MOD08, where the **first bin** included L2 pixel values equal to both the lower and higher bin boundary.

Appendix B:

Joint Histogram Statistics
&
Bin Boundaries

Joint Histogram Statistics and Bin Boundaries

Identical in Daily & Monthly Products

All Clouds

Parameter 1	(Bins): Bin Boundaries *	Parameter 2	(Bins): Bin Boundaries *	D/N
Cloud Top Pressure (hPa)	(14): 0, 120, 200, 280, 360, 440, 520, 600, 680, 760, 840, 920, 1000, 1080, 1120	Effective Emissivity	(6): 0.0, 0.2, 0.4, 0.6, 0.8, 0.95, 1.0	D N D+N
Cloud Top Pressure (hPa)	(14): 0, 120, 200, 280, 360, 440, 520, 600, 680, 760, 840, 920, 1000, 1080, 1120	Cloud Top Pressure Uncertainty (%)	(21): 0, 2, 4, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 150, 200	D N D+N
Cloud Top Temperature (K)	(20): 150, 180, 190, 200, 210, 220, 225, 230, 235, 240, 245, 250, 255, 260, 265, 270, 275, 280, 285, 290, 320	Cloud Top Pressure	(3): 0, 440, 680, 1100	D N D+N
Cloud Top Temperature (K)	(20): 150, 180, 190, 200, 210, 220, 225, 230, 235, 240, 245, 250, 255, 260, 265, 270, 275, 280, 285, 290, 320	Cloud Top Temperature Uncertainty (%)	(21): 0, 2, 4, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 150, 200	D N D+N
Cloud Top Height (meters)	(12): 0, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10000, 11000, 12000, 13000, 14000, 15000,16000, 17000, 18000	Cloud Top Pressure (hPa)	(3): 0, 440, 680, 1100	D N D+N
Cloud Top Height (meters)	(12): 0, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10000, 11000, 12000, 13000, 14000, 15000,16000, 17000, 18000	Cloud Top Height Uncertainty (%)	(21): 0, 2, 4, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 150, 200	D N D+N
Effective Emissivity (same as first JH, reversed, but different bins, probably not needed, but included to match MODIS Standard MOD08)	(11): 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 1.0	Cloud Top Pressure (hPa)	(10): 0, 80, 200, 320, 440, 560, 680, 800, 920, 1040, 1100	D N D+N

All Clouds (continued)

Parameter 1	(Bins): Bin Boundaries *	Parameter 2	(Bins): Bin Boundaries *	D/N
Cloud Phase Optical Properties	1.5, 2.5, 3.5, 4.5 2 = Liquid Water Clouds 3 = Ice Clouds 4 = Undetermined Clouds	Cloud Top Temperature (K)	(17): 190, 200, 210, 220, 225, 230, 235, 240, 245, 250, 255, 260, 265, 270, 275, 280, 285, 310	D
Optical Thickness ISCCP	(8): 0, 0.3, 1.3, 3.6, 9.4, 23, 60, 100, 150	Cloud Top Pressure ISCCP (hPA)	(7): 0, 180, 310, 440, 560, 680, 800, 1100	D

Liquid Water Clouds

Parameter 1	(Bins): Bin Boundaries *	Parameter 2	(Bins): Bin Boundaries *	D/N
Optical Thickness	(12): 0, 2, 4, 6, 8, 10, 15, 20, 30, 40, 50, 100, 150	Effective Radius (µm)	(9): 4, 6, 8, 10, 12.5, 15, 17.5, 20, 25, 30	D
Optical Thickness	(12): 0, 2, 4, 6, 8, 10, 15, 20, 30, 40, 50, 100, 150	Cloud Top Temperature (K)	(12): 190, 230, 240, 245, 250, 255, 260, 265, 270, 275, 280, 285, 310	D
Optical Thickness	(12): 0, 2, 4, 6, 8, 10, 15, 20, 30, 40, 50, 100, 150	Cloud Top Pressure (hPA)	(13): 50, 250, 300, 350, 400, 450, 500, 550, 600, 700, 800, 900, 1000, 1100	D
Optical Thickness	(12): 0, 2, 4, 6, 8, 10, 15, 20, 30, 40, 50, 100, 150	Optical Thickness Uncertainty (%)	(21): 0, 2, 4, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 150, 200	D
Effective Radius (µm)	(9): 4, 6, 8, 10, 12.5, 15, 17.5, 20, 25, 30	Cloud Top Temperature (K)	(12): 190, 230, 240, 245, 250, 255, 260, 265, 270, 275, 280, 285, 310	D
Effective Radius (µm)	(9): 4, 6, 8, 10, 12.5, 15, 17.5, 20, 25, 30	Cloud Top Pressure (hPA)	(13): 50, 250, 300, 350, 400, 450, 500, 550, 600, 700, 800, 900, 1000, 1100	D
Effective Radius (µm)	(9): 4, 6, 8, 10, 12.5, 15, 17.5, 20, 25, 30	Effective Radius Uncertainty (%)	(21): 0, 2, 4, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 150, 200	D
Cloud Water Path (g/m)	(15): 0, 10, 20, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 1000, 2000, 3000	Cloud Water Path Uncertainty (%)	(21): 0, 2, 4, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 150, 200	D

Ice Clouds

Parameter 1	(Bins): Bin Boundaries *	Parameter 2	(Bins): Bin Boundaries *	D/N
Optical Thickness	(12): 0, 0.5, 1, 2.5, 5, 7.5, 10, 15, 20, 30, 50, 100, 150	Effective Radius (μm)	(11): 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60	D
Optical Thickness	(12): 0, 0.5, 1, 2.5, 5, 7.5, 10, 15, 20, 30, 50, 100, 150	Cloud Top Temperature (K)	(13): 190, 200, 210, 220, 225, 230, 235, 240, 245, 250, 255, 260, 265, 270	D
Optical Thickness	(12): 0, 0.5, 1, 2.5, 5, 7.5, 10, 15, 20, 30, 50, 100, 150	Cloud Top Pressure (hPa)	(16): 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 700, 800, 900, 1000, 1100	D
Optical Thickness	(12): 0, 0.5, 1, 2.5, 5, 7.5, 10, 15, 20, 30, 50, 100, 150	Effective Emissivity	(10): 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0	D
Optical Thickness	(12): 0, 0.5, 1, 2.5, 5, 7.5, 10, 15, 20, 30, 50, 100, 150	Optical Thickness Uncertainty (%)	(21): 0, 2, 4, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 150, 200	D
Effective Radius (μm)	(11): 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60	Cloud Top Temperature (K)	(13): 190, 200, 210, 220, 225, 230, 235, 240, 245, 250, 255, 260, 265, 270	D
Effective Radius (μm)	(11): 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60	Cloud Top Pressure (hPa)	(16): 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 700, 800, 900, 1000, 1100	D
Effective Radius (μm)	(11): 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60	Effective Radius Uncertainty (%)	(21): 0, 2, 4, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 150, 200	D

* Bin Boundary Handling: For L3 CLDPROP Joint Histograms, the first through the next to last histogram bin includes L2 pixel values equal to the lower bin boundary. The **last bin** includes L2 pixel values equal to both the lower and the higher bin boundary. This is slightly different from MODIS Standard MOD08, where the **first bin** included L2 pixel values equal to both the lower and higher bin boundary.

Note that joint histogram bin boundary defintions for all supplemental retrievals of Cloud Optical Property Parameters (16, 37, and 1621) are the same as the primary (21) shown in the Table.

Appendix C:

Information Provided to Users to Assist in Developing Grid-Level Uncertainty Calculation Software or Tools that utilize Uncertainly Joint Histograms prodvided in L3 CLDPROP

Detailed in this Appendix is our old MODIS Standard L3 Uncertainty computation code taken from the MOD08-MODIS L3 Tiling code. This is provided as a possible aid to power users of this data to develop methods, software, and tools to compute L3 grid-level uncertainly using the Joint Histograms vs. Uncertainty provided in the CLDPROP L3 products.

Users should be aware that uncertainties derived from Joint Histogram data are only immediately useful for L3 Daily data (D3), not Monthly (M3). However, at this time, the L3 gridding code creates a Monthly (M3) aggregation by default.

Note that for the **JHisto_vs_Uncertainty** arrays, the Uncertainty will be in relative (%) units. This will require post processing to convert the relative % uncertainties to absolute uncertainties (in the units of the parameter in question) by evaluating the mid points of each joint histogram bin. With that conversion done, users could them compute the actual uncertainty in each L3 1x1 degree grid.

Note that for Cloud Top Properties, the L2 pixel-level uncertainty is computed directly for Cloud_Top_Temperature only. For Cloud Optical Properties, the L2 pixel-level uncertainty is computed directly for Cloud_Optical_Thickness and Cloud_Effective_Radius only. For other parameters in the CLDPROP file (not all listed here), the uncertainties are derived. For example the parameters Cloud_Top_Pressure, Cloud_Top_Height, and Cloud Water_Path have derived uncertainties.

Method used for Uncertainty Calculation in the L3 MODIS Standard (MOD08) Data:

Given below is our old MODIS Standard L3 Uncertainty computation code taken from the MOD08-MODIS L3 Tiling code.

FOR EACH 1x1 degree L3 grid cell, the **size(values)** is the number of L2 pixel data in each 1x1 deg. L3 grid. For example, the number of Cloud Optical Thickness retrievals in a L3 1x1 grid. This corresponds to the total pixel counts, which for our Yori JH arrays, will be the sum of the pixel counts in the entire Joint Histogram (sum up all the JH bin boxes containing counts).

```
!------------------------------------------------------
! --- DEFINE CORRELATION MATRIX
!------------------------------------------------------

!--- Set the correlation from 0.0 to 1.0 (we will use 1.0 for now)
        correlation = 1.0

!--- Fill the entire corr array (including the important non-diaginals)
!---     to the correlation value specified above,
!---     the diagonals will be hardwired to 1, below
        corr = correlation

!--- Set the diaginals in the corr array to 1.0 (don't change this!)
        Do i=1,size(values)
           corr(i,i) = 1.0
        End do

```

Farther down in the Tiling code is this section of logic:

```
!---------------------------------------------------------------
! --- COMPUTE L3 GRID LEVEL UNCERTAINTY
!---------------------------------------------------------------
! Compute Regular Uncertainty (Weights NOT present)
!   Values below is the primary parameter
!   jointValues below is the relative uncertainty (in percent)
!
!
!       print *,' '
!       print *,' REGULAR  '
!       print *,' Values = ',values(:)
!       print *,' jointValues = ',jointValues(:)
!       print *,' size(values) = ',size(values)


!--- S.Platnick's Original Equation
!       variance = (sum((jointValues(:)*values(:)/100.0)**2)) / (size(values)**2)
!       Uncert = sqrt(variance)


!--- S.Platnick's Updated Equation
        a = jointValues*values/100.0
        x = reshape(a,(/size(values),1/))
        y = reshape(a,(/1,size(values)/))

       variance = sum(corr*matmul(x,y))/(size(values)**2)
       Uncert = sqrt(variance)

!       print *,' Mean_Uncertainty = ',Uncert

```

Note: There are two F90 functions listed in the code above: reshape and matmul.

In order to proved as much details here as possible, what follows is documentation on those 2 functions.

RESHAPE Function

Description

The RESHAPE function constructs an array of a specified shape from a template array. Function to reshape an array

Syntax

RESULT = RESHAPE (*source*, *shape [*, *pad] [*, *order]*)

Required Arguments

source is an INTENT(IN) array of any type. If *pad* is absent or of size zero, the size of *source* must be greater than or equal to the product of the values of the elements of *shape*.

shape is an INTENT(IN) INTEGER array of rank one. Its size must be positive and less than or equal to seven. It cannot have any negative elements.

Optional Arguments

pad is an INTENT(IN) array of the same type and kind as *source*.

order is an INTENT(IN) array of type INTEGER with the same shape as *shape*. Its value must be a permutation of (1, 2, ..., n), where *n* is the size of *order*. If *order* is absent, it is as if it were present with the value (1, 2, ..., n).

Result

The result is an array of the same type and kind as *source*, with a shape identical to *shape*.

The elements of the result, taken in permuted subscript order, order(1), ..., order(n), are those of *source* in array element order followed if necessary by elements of one or more copies of *pad* in array element order.

Example

```
real :: x.(4)
real :: x.(2,2)=reshape((/1.,2.,3.,4./),shape(x2))
real :: x.(3,2)
x1=reshape(x2,shape(x1))
write(*,*) x. ! writes 1. 2. 3. 4.
write(*,*) reshape(x1,shape(x2),order=(/2,1/))
            ! writes 1. 3. 2. 4.
write(*,*) reshape(x1,shape(x3),pad=(/0./))
            ! writes 1. 2. 3. 4. 0. 0.
```

MATMUL Function

Description

The MATMUL function multiplies two matrices.

Syntax

MATMUL (*matrix_a*, *matrix_b*)

Arguments

matrix_a is an INTENT(IN) array of type INTEGER, REAL, COMPLEX, or LOGICAL. It may be either rank one or two if *matrix_b* is of rank two, and must be of rank two if *matrix_b* is rank one.

matrix_b is an INTENT(IN) array of numerical type if *matrix_a* is of numerical type, and of LOGICAL type if *matrix_a* is of LOGICAL type. It may be of rank one or two if *matrix_a* is of rank two, and must be of rank two if *matrix_a* is of rank one.

The size of the first dimension must be the same as the size of the last dimension of *matrix_a*.

Result

If the arguments are of the same numeric type and kind, the result is of that type and kind. If their kind is different, the result kind is that with higher precision.

If the arguments are of different numeric types and neither is of type COMPLEX, the result is of type REAL.

If one or both of the arguments are of type COMPLEX, then the result is COMPLEX.

If the arguments are of type LOGICAL, the result is of type LOGICAL. If their kinds are the same, the result kind is that of the arguments. If their kind is different, the result kind is that of the argument with the greater kind parameter.

The value and shape of the result are as follows:

If *matrix_a* has shape (n, m) and *matrix_b* has shape (m, k), the result has shape (n, k). Element (i, j) of the result has the value *SUM(matrix_a(i, :) * matrix_b(:, j))* if the arguments are of numeric type and has the value *ANY(matrix_a(i, :) * matrix_b(:, j))* if the arguments are of type LOGICAL.

If *matrix_a* has shape (m) and *matrix_b* has shape (m, k), the result has shape (k). Element (j) of the result has the value *SUM(matrix_a(:) * matrix_b(:, j))* if the arguments are of numeric type and has the value *ANY(matrix_a(:) * matrix_b(:, j))* if the arguments are of type LOGICAL.

If *matrix_a* has shape (n, m) and *matrix_b* has shape (m), the result has shape (n). Element (i, j) of the result has the value *SUM(matrix_a(i, :) * matrix_b(:))* if the arguments are of numeric type and has the value *ANY(matrix_a(i, :) * matrix_b(:))* if the arguments are of type LOGICAL.

Example

```
integer :: a1(2,3),a5(5,2),b3(3),b2(2)
complex :: c2(2)
a1=reshape((/1,2,3,4,5,6/),shape(a1))
a5=reshape((/0,1,2,3,4,5,6,7,8,9/),shape(a5))
b2=(/1,2/)
b3=(/1,2,3/)
write(*,"(2i3)") a1 ! writes  1  2
               !        3  4
               !        5  6
write(*,*) matmul(a1,b3) ! writes 22 28
write(*,*) matmul(b2,a1) ! writes 5 11 17
write(*,"(5i3)") a5 ! writes  0  1  2  3  4
               !        5  6  7  8  9
write(*,"(5i3)") matmul(a5,a1) ! writes 10 13 16 19 22
                        !       20 27 34 41 48
                        !       30 41 52 63 74
c2=(/(-1.,1.),(1.,-1.)/)
write(*,*) matmul(a5,c2) ! writes (5.,-5.) five times
```

Appendix D:

Sample Global Attributes in a L3 CLDPROP File

The information that follows in this Appendx, provides users with an idea of the kind and scope of information that will be seen at the top (in the global attribute section) of any given NetCDF4 CLDPROP L3 file.

netcdf CLDPROP_M3_VIIRS_SNPP.A2014032.001.2019165170930 {

// global attributes:

```
                :Yori_version = "1.3.6" ;
                :daily = "False" ;

                :input_files = 
"CLDPROP_D3_VIIRS_SNPP.A2014032.001.2019165161056.nc,CLDPROP_D3_VIIRS_SNPP
.A2014033.001.2019165161229.nc,CLDPROP_D3_VIIRS_SNPP.A2014034.001.20191651
61209.nc,CLDPROP_D3_VIIRS_SNPP.A2014035.001.2019165160845.nc,CLDPROP_D3_VI
IRS_SNPP.A2014036.001.2019165160927.nc,CLDPROP_D3_VIIRS_SNPP.A2014037.001.
2019165160951.nc,CLDPROP_D3_VIIRS_SNPP.A2014038.001.2019165160932.nc,CLDPR
OP_D3_VIIRS_SNPP.A2014039.001.2019165160936.nc,CLDPROP_D3_VIIRS_SNPP.A2014
040.001.2019165161202.nc,CLDPROP_D3_VIIRS_SNPP.A2014041.001.2019165161142.
nc,CLDPROP_D3_VIIRS_SNPP.A2014042.001.2019165160948.nc,CLDPROP_D3_VIIRS_SN
PP.A2014043.001.2019165161218.nc,CLDPROP_D3_VIIRS_SNPP.A2014044.001.201916
5160933.nc,CLDPROP_D3_VIIRS_SNPP.A2014045.001.2019165160933.nc,CLDPROP_D3_
VIIRS_SNPP.A2014046.001.2019165161039.nc,CLDPROP_D3_VIIRS_SNPP.A2014047.00
1.2019165161025.nc,CLDPROP_D3_VIIRS_SNPP.A2014048.001.2019165161035.nc,CLD
PROP_D3_VIIRS_SNPP.A2014049.001.2019165160943.nc,CLDPROP_D3_VIIRS_SNPP.A20
14050.001.2019165160923.nc,CLDPROP_D3_VIIRS_SNPP.A2014051.001.201916516092
8.nc,CLDPROP_D3_VIIRS_SNPP.A2014052.001.2019165160931.nc,CLDPROP_D3_VIIRS_
SNPP.A2014053.001.2019165160942.nc,CLDPROP_D3_VIIRS_SNPP.A2014054.001.2019
165160936.nc,CLDPROP_D3_VIIRS_SNPP.A2014055.001.2019165161034.nc,CLDPROP_D
3_VIIRS_SNPP.A2014056.001.2019165161025.nc,CLDPROP_D3_VIIRS_SNPP.A2014057.
001.2019165160921.nc,CLDPROP_D3_VIIRS_SNPP.A2014058.001.2019165160927.nc,C
LDPROP_D3_VIIRS_SNPP.A2014059.001.2019165160927.nc" ;

                :history = "" ;
                :source = "CLDPROP_L2_VIIRS 1.0, cldprop_preyori 20190613-
1, idl 8.4, yori 1.3.6" ;
                :date_created = "2019-06-14T17:06:31Z" ;
                :product_name = 
"CLDPROP_M3_VIIRS_SNPP.A2014032.001.2019165170930.nc" ;
                :LocalGranuleID = 
"CLDPROP_M3_VIIRS_SNPP.A2014032.001.2019165170930.nc" ;
                :Conventions = "CF-1.6, ACDD-1.3" ;
                :ShortName = "CLDPROP_M3_VIIRS_SNPP" ;
                :product_version = "1.0dev8" ;
                :AlgorithmType = "SCI" ;
                :identifier_product_doi = 
"10.5067/VIIRS/CLDPROP_M3_VIIRS_SNPP.001" ;
                :identifier_product_doi_authority = "http://dx.doi.org" ;
                :ancillary_files = "" ;
                :DataCenterId = "UWI-MAD/SSEC/ASIPS" ;
                :project = "NASA VIIRS Atmosphere SIPS" ;
                :creator_name = "NASA VIIRS Atmosphere SIPS" ;
```

```
		:creator_url = "https://sips.ssec.wisc.edu" ;
		:creator_email = "sips.support@ssec.wisc.edu" ;
		:creator_institution = "Space Science & Engineering Center,
University of Wisconsin - Madison" ;
		:publisher_name = "LAADS" ;
		:publisher_url = "https://ladsweb.modaps.eosdis.nasa.gov/"
;
		:publisher_email = "modis-ops@lists.nasa.gov" ;
		:publisher_institution = "NASA Level-1 and Atmosphere
Archive & Distribution System" ;
		:time_coverage_start = "2014-02-01T00:00:00.000000" ;
		:time_coverage_end = "2014-02-28T23:59:59.000000" ;
		:xmlmetadata = "<?xml version=\"1.0\"?>\n<!DOCTYPE
GranuleMetaDataFile SYSTEM
\"http://ecsinfo.gsfc.nasa.gov/ECSInfo/ecsmetadata/dtds/DPL/ECS/ScienceGra
nuleMetadata.dtd\">\n<GranuleMetaDataFile>\n  <DTDVersion>1.0</DTDVersion>
\n  <DataCenterId>UWI-
MAD/SSEC/ASIPS</DataCenterId>\n  <GranuleURMetaData>\n    <CollectionMetaD
ata>\n      <ShortName>CLDPROP_M3_VIIRS_SNPP</ShortName>\n      <VersionID
>1</VersionID>\n    </CollectionMetaData>\n    <ECSDataGranule>\n      <Re
processingPlanned>no further reprocessing
anticipated</ReprocessingPlanned>\n      <LocalGranuleID>CLDPROP_M3_VIIRS_
SNPP.A2014032.001.2019165170930.nc</LocalGranuleID>\n      <ProductionDate
Time>2019-06-14
17:32:59.736300</ProductionDateTime>\n      <LocalVersionID>1</LocalVersio
nID>\n    </ECSDataGranule>\n    <PGEVersionClass>\n      <PGEVersion>1.0d
ev8</PGEVersion>\n    </PGEVersionClass>\n    <RangeDateTime>\n      <Rang
eEndingTime>23:59:59.000000</RangeEndingTime>\n      <RangeEndingDate>2014
-02-
28</RangeEndingDate>\n      <RangeBeginningTime>00:00:00.000000</RangeBegi
nningTime>\n      <RangeBeginningDate>2014-02-
01</RangeBeginningDate>\n    </RangeDateTime>\n    <SpatialDomainContainer
>\n      <HorizontalSpatialDomainContainer>\n        <BoundingRectangle>\n
          <WestBoundingCoordinate>-
180</WestBoundingCoordinate>\n          <NorthBoundingCoordinate>90</North
BoundingCoordinate>\n          <EastBoundingCoordinate>180</EastBoundingCo
ordinate>\n          <SouthBoundingCoordinate>-
90</SouthBoundingCoordinate>\n        </BoundingRectangle>\n      </Horizo
ntalSpatialDomainContainer>\n    </SpatialDomainContainer>\n    <OrbitCalc
ulatedSpatialDomain>\n      <OrbitCalculatedSpatialDomainContainer>\n
   <OrbitNumber>None</OrbitNumber>\n      </OrbitCalculatedSpatialDomainCo
ntainer>\n    </OrbitCalculatedSpatialDomain>\n    <Platform>\n      <Plat
formShortName>Suomi
NPP</PlatformShortName>\n      <Instrument>\n        <InstrumentShortName>
VIIRS</InstrumentShortName>\n        <Sensor>\n          <SensorShortName>
VIIRS</SensorShortName>\n        </Sensor>\n      </Instrument>\n    </Pla
tform>\n    <InputGranule>\n      <InputPointer>CLDPROP_D3_VIIRS_SNPP.A201
4032.001.2019165161056.nc</InputPointer>\n      <InputPointer>CLDPROP_D3_V
IIRS_SNPP.A2014033.001.2019165161229.nc</InputPointer>\n      <InputPointe
r>CLDPROP_D3_VIIRS_SNPP.A2014034.001.2019165161209.nc</InputPointer>\n
  <InputPointer>CLDPROP_D3_VIIRS_SNPP.A2014035.001.2019165160845.nc</Input
Pointer>\n      <InputPointer>CLDPROP_D3_VIIRS_SNPP.A2014036.001.201916516
0927.nc</InputPointer>\n      <InputPointer>CLDPROP_D3_VIIRS_SNPP.A2014037
.001.2019165160951.nc</InputPointer>\n      <InputPointer>CLDPROP_D3_VIIRS
_SNPP.A2014038.001.2019165160932.nc</InputPointer>\n      <InputPointer>CL
DPROP_D3_VIIRS_SNPP.A2014039.001.2019165160936.nc</InputPointer>\n      <I
nputPointer>CLDPROP_D3_VIIRS_SNPP.A2014040.001.2019165161202.nc</InputPoin
```

```
ter>\n      <InputPointer>CLDPROP_D3_VIIRS_SNPP.A2014041.001.2019165161142
.nc</InputPointer>\n      <InputPointer>CLDPROP_D3_VIIRS_SNPP.A2014042.001
.2019165160948.nc</InputPointer>\n      <InputPointer>CLDPROP_D3_VIIRS_SNP
P.A2014043.001.2019165161218.nc</InputPointer>\n      <InputPointer>CLDPRO
P_D3_VIIRS_SNPP.A2014044.001.2019165160933.nc</InputPointer>\n      <Input
Pointer>CLDPROP_D3_VIIRS_SNPP.A2014045.001.2019165160933.nc</InputPointer>
\n      <InputPointer>CLDPROP_D3_VIIRS_SNPP.A2014046.001.2019165161039.nc<
/InputPointer>\n      <InputPointer>CLDPROP_D3_VIIRS_SNPP.A2014047.001.201
9165161025.nc</InputPointer>\n      <InputPointer>CLDPROP_D3_VIIRS_SNPP.A2
014048.001.2019165161035.nc</InputPointer>\n      <InputPointer>CLDPROP_D3
_VIIRS_SNPP.A2014049.001.2019165160943.nc</InputPointer>\n      <InputPoin
ter>CLDPROP_D3_VIIRS_SNPP.A2014050.001.2019165160923.nc</InputPointer>\n
    <InputPointer>CLDPROP_D3_VIIRS_SNPP.A2014051.001.2019165160928.nc</Inp
utPointer>\n      <InputPointer>CLDPROP_D3_VIIRS_SNPP.A2014052.001.2019165
160931.nc</InputPointer>\n      <InputPointer>CLDPROP_D3_VIIRS_SNPP.A20140
53.001.2019165160942.nc</InputPointer>\n      <InputPointer>CLDPROP_D3_VII
RS_SNPP.A2014054.001.2019165160936.nc</InputPointer>\n      <InputPointer>
CLDPROP_D3_VIIRS_SNPP.A2014055.001.2019165161034.nc</InputPointer>\n
<InputPointer>CLDPROP_D3_VIIRS_SNPP.A2014056.001.2019165161025.nc</InputPo
inter>\n      <InputPointer>CLDPROP_D3_VIIRS_SNPP.A2014057.001.20191651609
21.nc</InputPointer>\n      <InputPointer>CLDPROP_D3_VIIRS_SNPP.A2014058.0
01.2019165160927.nc</InputPointer>\n      <InputPointer>CLDPROP_D3_VIIRS_S
NPP.A2014059.001.2019165160927.nc</InputPointer>\n    </InputGranule>\n

<AncillaryInputGranules>\n    </AncillaryInputGranules>\n  </GranuleURMeta
Data>\n</GranuleMetaDataFile>" ;
               :platform = "Suomi-NPP" ;
               :instrument = "VIIRS" ;
               :processing_level = "L3" ;
               :format = "NetCDF4" ;
               :title = "SNPP VIIRS Cloud Properties Level 3 monthly, 1x1
degree grid (CLDPROP_M3_VIIRS_SNPP)" ;
               :long_name = "VIIRS/SNPP Cloud Properties Level 3 monthly,
1x1 degree grid" ;
               :version_id = "001" ;
               :geospatial_lat_max = 90. ;
               :geospatial_lat_min = -90. ;
               :geospatial_lon_min = 180. ;
               :geospatial_lon_max = -180. ;
               :NorthBoundingCoordinate = 90. ;
               :SouthBoundingCoordinate = -90. ;
               :EastBoundingCoordinate = 180. ;
               :WestBoundingCoordinate = -180. ;
               :latitude_resolution = 1. ;
               :longitude_resolution = 1. ;
               :license = "http://science.nasa.gov/earth-science/earth-
science-data/data-information-policy/" ;
               :stdname_vocabulary = "NetCDF Climate and Forecast (CF)
Metadata Convention" ;
               :keywords_vocabulary = "NASA Global Change Master Directory
(GCMD) Science Keywords" ;
               :keywords = "EARTH SCIENCE > ATMOSPHERE > CLOUDS > CLOUD
MICROPHYSICS > CLOUD OPTICAL DEPTH/THICKNESS, EARTH SCIENCE > ATMOSPHERE >
CLOUDS > CLOUD PROPERTIES > CLOUD TOP HEIGHT, EARTH SCIENCE > ATMOSPHERE >
CLOUDS > CLOUD PROPERTIES > CLOUD FRACTION" ;
               :naming_authority = "gov.nasa.gsfc.sci.atmos" ;
```

Appendix E:

Flow Chart of the
SIPS-Yori
Continuity L3 Processing System

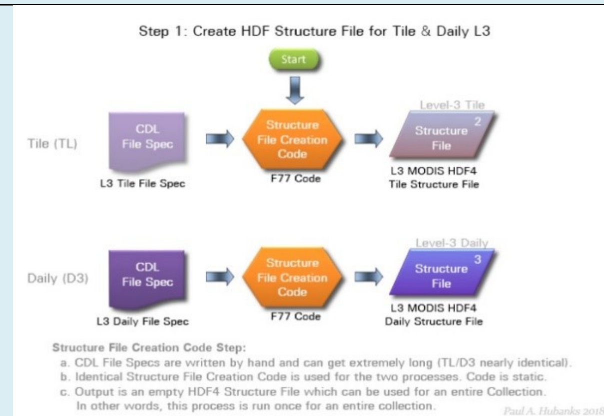
And How it Compares to the
MODAPS / MODIS Standard
L3 Processing System

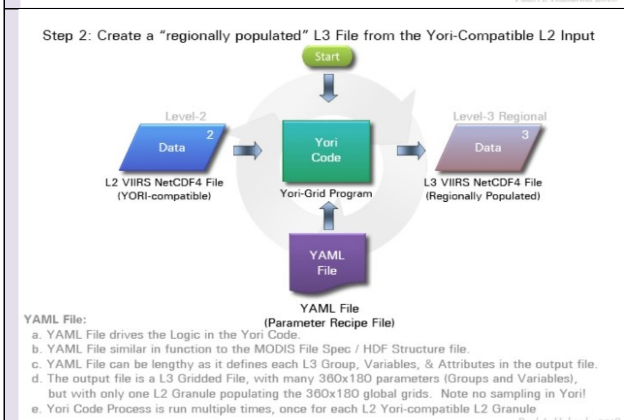
Flow Comparison SIPS-YORI vs. MODAPS Processes

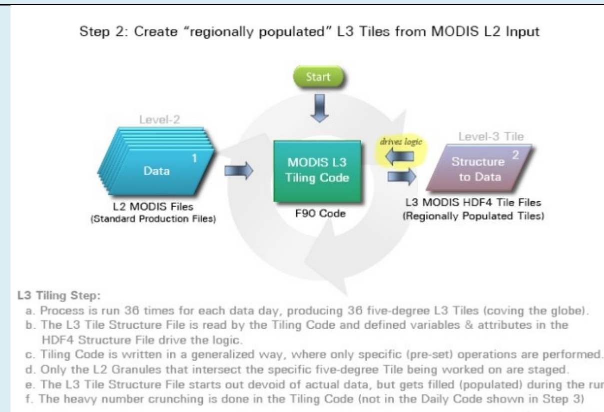
Atmosphere Level-3

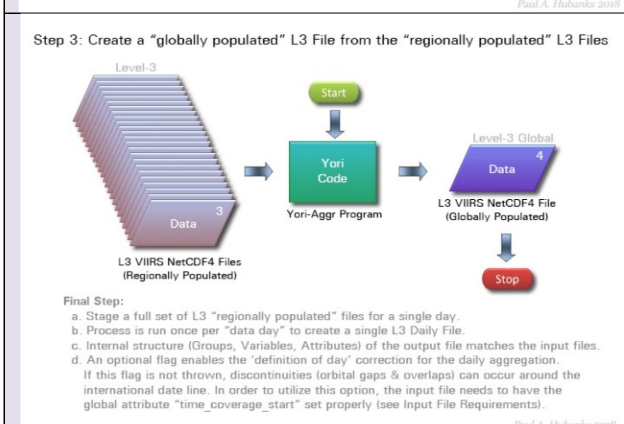
These flowcharts are provided as background information to the user community on how the L3 Products are made. Compared here is the new SIPS-Yori system vs. the old MODAPS system. It's interesting to note some general similarities between these two Processing Systems.

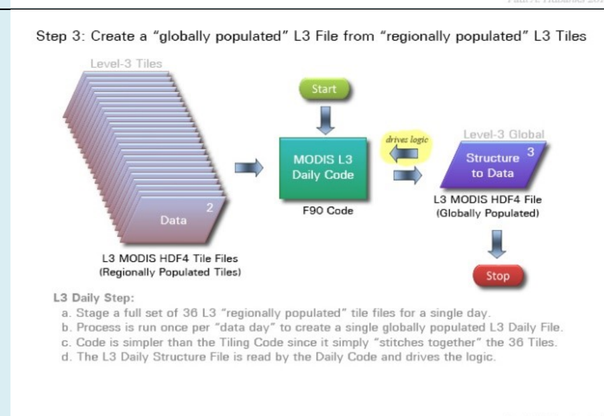
SIPS-YORI / Continuity	MODAPS / MODIS Std







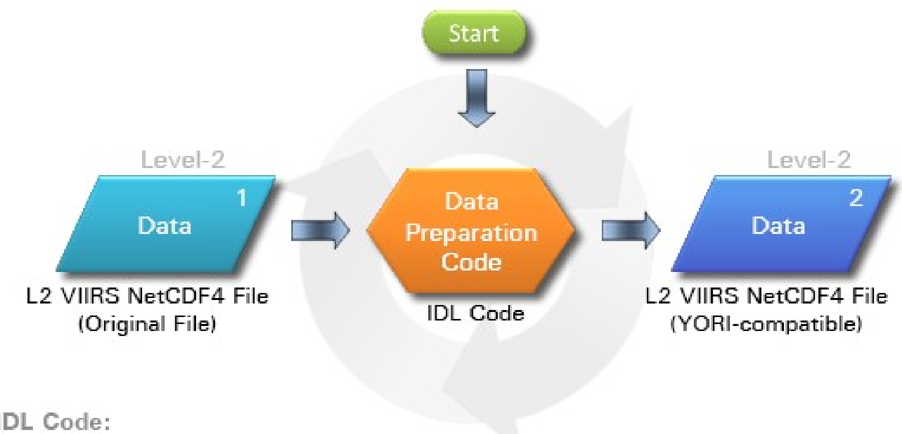




Flow Chart for SIPS-YORI Process

Continuity Atmosphere Level-3

Step 1: Create new modified L2 Input Files so they can be ingested by Yori



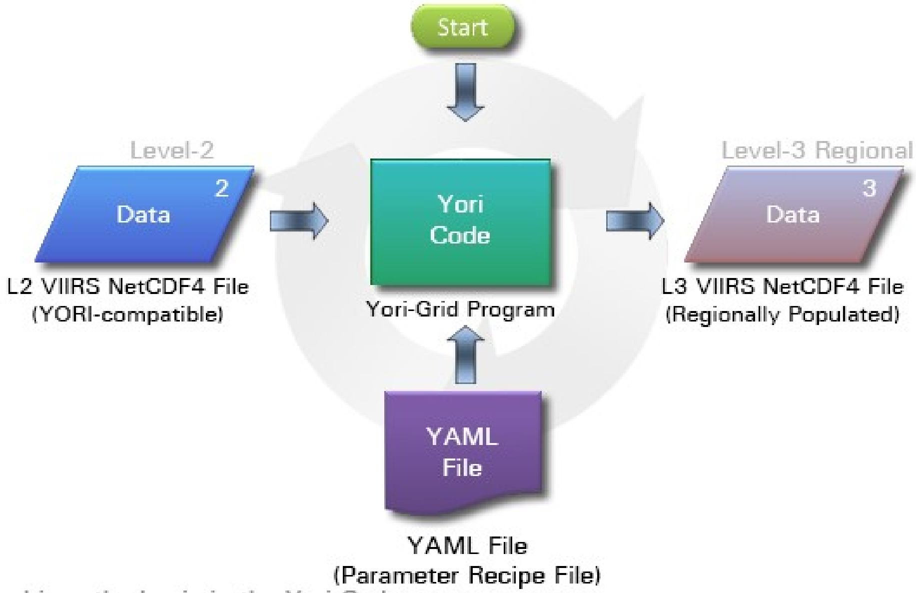
IDL Code:

a. Open and Read the Input VIIRS L2 NetCDF4 File.
b. Loop through Input File Variables and write needed Variables to new file.
c. Create new Variables if needed (e.g. Fraction Statistics & Log Statistics) and write to new file. This enhancement will be tackled after initial phase (computing default simple statistics) is completed.
d. Read QA, Create Flat Filtering Masks, and write to new file.
e. Input and Output Files are a single L2 Granule.
f. Data Preparation Code Process is run multiple times, once for each L2 VIIRS Granule.

Paul A. Hubanks 2018

Note: The light-gray large flat circular arrow under the "Data Preparation Code" symbol (orange hexagon) denotes that code is looping (that is, it contains looping logic that iterates through each SDS), so that block can be an involved process.

Step 2: Create a "regionally populated" L3 File from the Yori-Compatible L2 Input



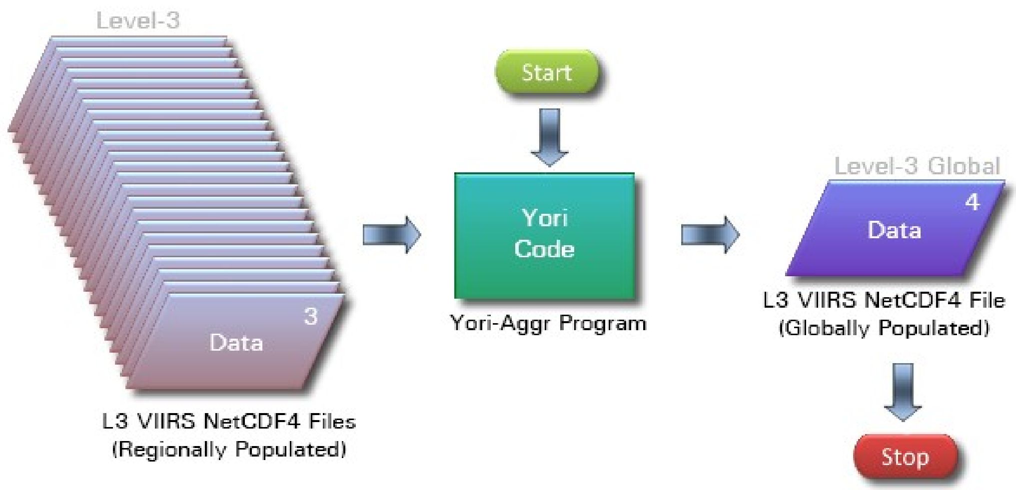
YAML File:

a. YAML File drives the Logic in the Yori Code.
b. YAML File similar in function to the MODIS File Spec / HDF Structure file.
c. YAML File can be lengthy as it defines each L3 Group, Variables, & Attributes in the output file.
d. The output file is a L3 Gridded File, with many 360x180 parameters (Groups and Variables), but with only one L2 Granule populating the 360x180 global grids. Note no sampling in Yori!
e. Yori Code Process is run multiple times, once for each L2 Yori-compatible L2 Granule

Paul A. Hubanks 2018

Note: The light-gray large flat circular arrow under the "Yori Code" block (green rectangle) denotes that code is looping (that is, it contains looping logic that iterates through each Group/Variable combination), so that block can be an involved process. The YAML File actually drives the logic and controls the looping in the Yori Code.

Step 3: Create a "globally populated" L3 File from the "regionally populated" L3 Files



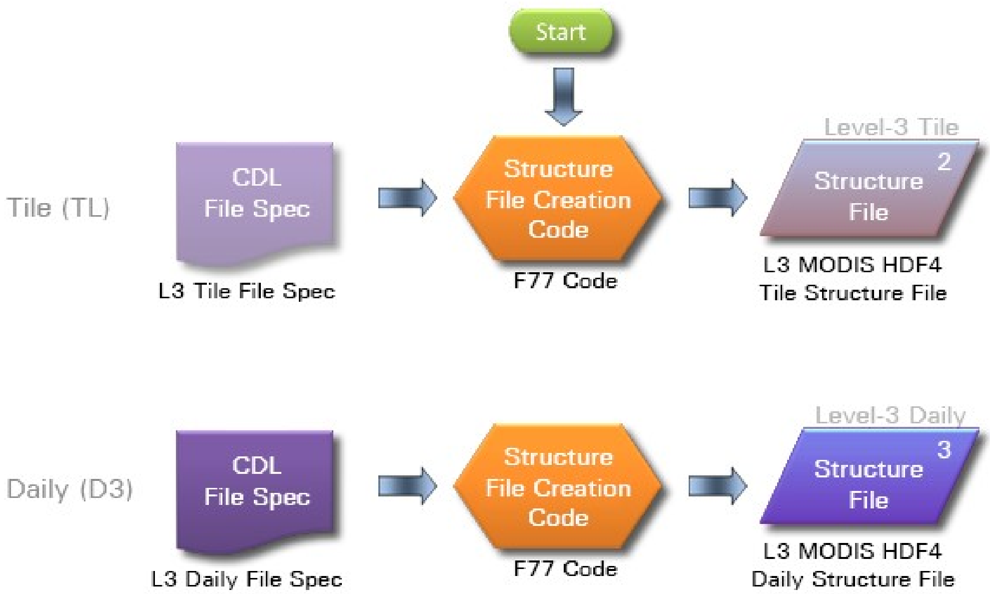
Final Step:

a. Stage a full set of L3 "regionally populated" files for a single day.
b. Process is run once per "data day" to create a single L3 Daily File.
c. Internal structure (Groups, Variables, Attributes) of the output file matches the input files.
d. An optional flag enables the 'definition of day' correction for the daily aggregation. If this flag is not thrown, discontinuities (orbital gaps & overlaps) can occur around the international date line. In order to utilize this option, the input file needs to have the global attribute "time_coverage_start" set properly (see Input File Requirements).

Paul A. Hubanks 2018

Flow Chart for MODAPS Process
MODIS Standard Level-3

Step 1: Create HDF Structure File for Tile & Daily L3

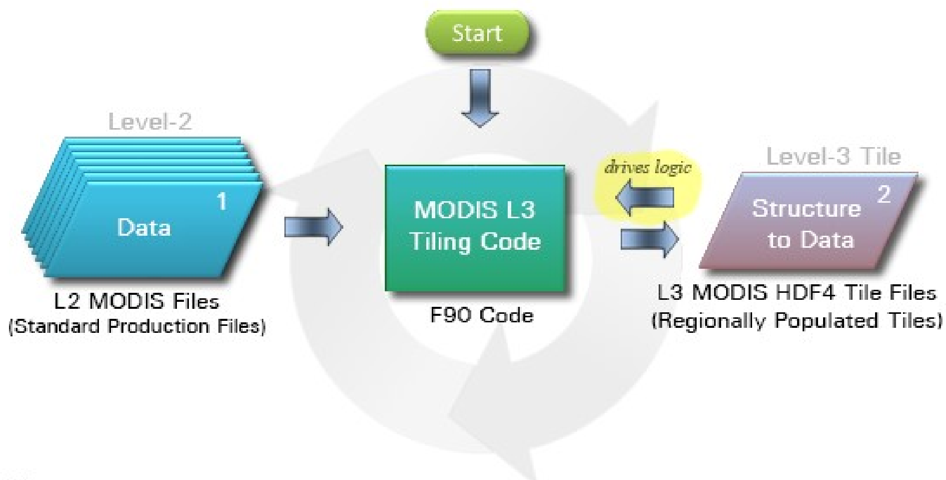


Structure File Creation Code Step:

a. CDL File Specs are written by hand and can get extremely long (TL/D3 nearly identical).
b. Identical Structure File Creation Code is used for the two processes. Code is static.
c. Output is an empty HDF4 Structure File which can be used for an entire Collection.
   In other words, this process is run once for an entire collection.

Paul A. Hubanks 2018

Step 2: Create "regionally populated" L3 Tiles from MODIS L2 Input

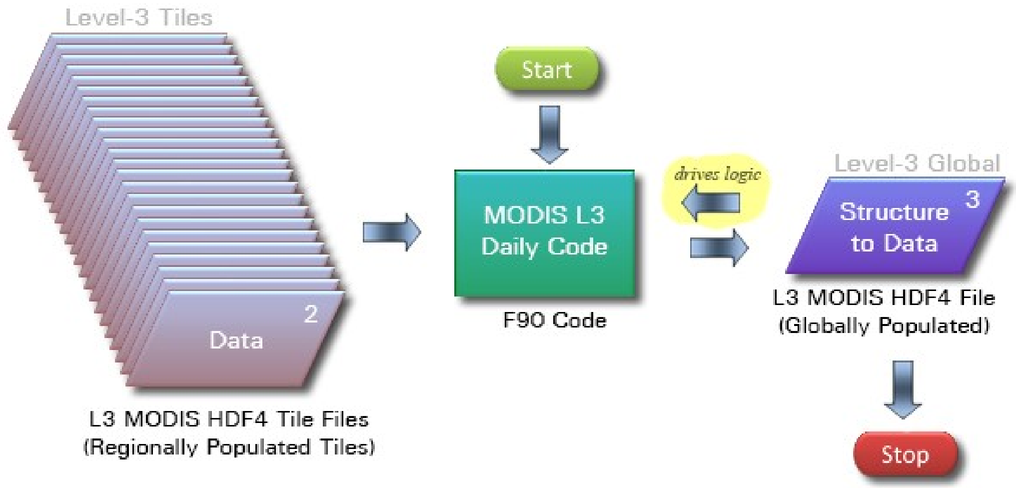


L3 Tiling Step:

a. Process is run 36 times for each data day, producing 36 five-degree L3 Tiles (coving the globe).
b. The L3 Tile Structure File is read by the Tiling Code and defined variables & attributes in the HDF4 Structure File drive the logic.
c. Tiling Code is written in a generalized way, where only specific (pre-set) operations are performed.
d. Only the L2 Granules that intersect the specific five-degree Tile being worked on are staged.
e. The L3 Tile Structure File starts out devoid of actual data, but gets filled (populated) during the run.
f. The heavy number crunching is done in the Tiling Code (not in the Daily Code shown in Step 3)

Paul A. Hubanks 2018

Step 3: Create a "globally populated" L3 File from "regionally populated" L3 Tiles



L3 Daily Step:

a. Stage a full set of 36 L3 "regionally populated" tile files for a single day.
b. Process is run once per "data day" to create a single globally populated L3 Daily File.
c. Code is simpler than the Tiling Code since it simply "stitches together" the 36 Tiles.
d. The L3 Daily Structure File is read by the Daily Code and drives the logic.

Paul A. Hubanks 2018